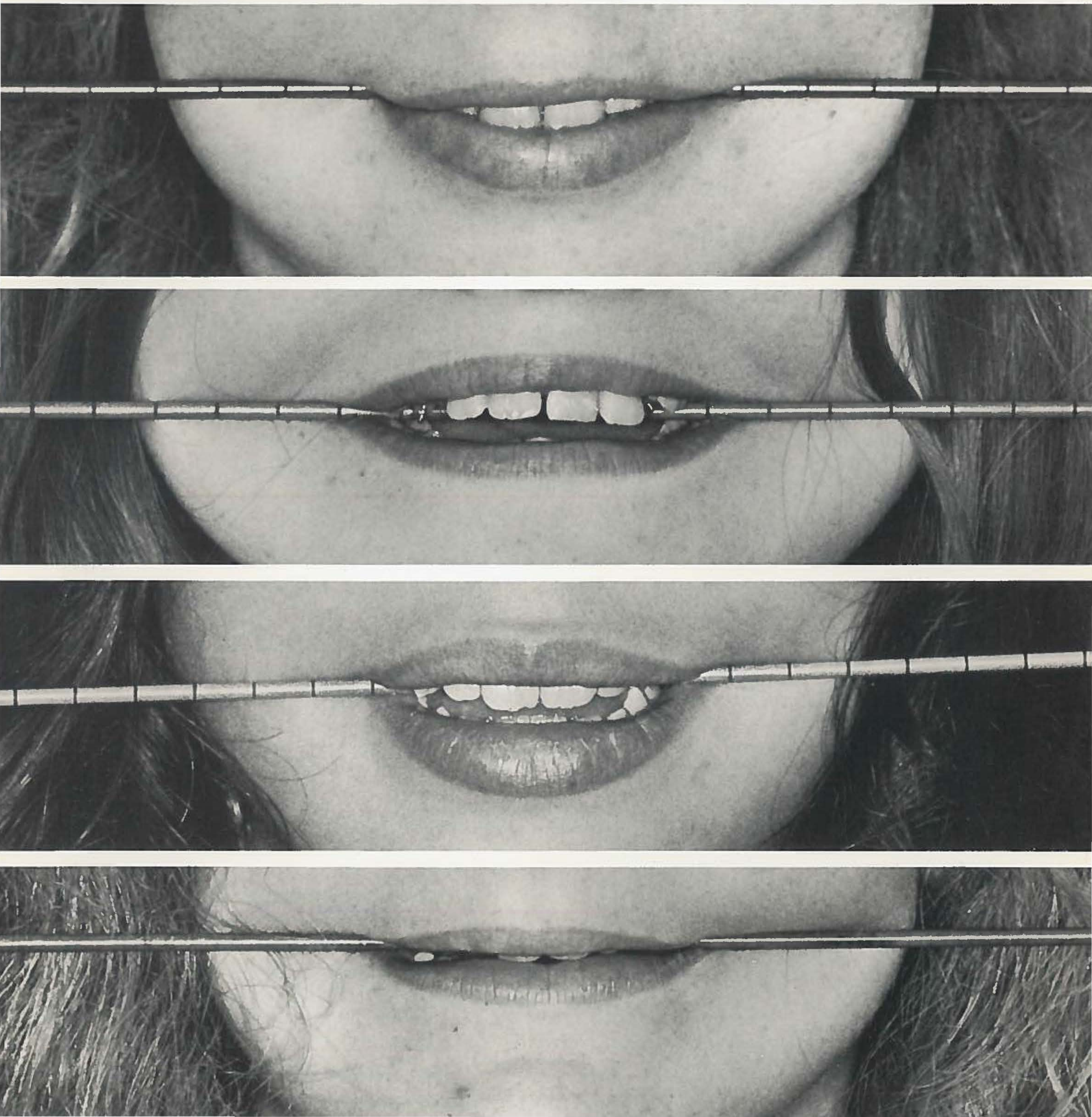
Juvenile temporomandibular joint dysfunction and craniofacial growth. A statistical analysis

Dibbets, Joseph Marie Henri

Juvenile Temporomandibular Joint Dysfunction and Craniofacial Growth / Jos Dibbets



Juvenile
Temporomandibular Joint Dysfunction
and Craniofacial Growth

From the Department of Oral Surgery, Chairman Prof. G. Boering, D. D. S., Ph. D. and the Department of Orthodontics, Chairman Prof. H. S. Duterloo, D. D. S., Ph. D. Faculty of Dentistry University of Groningen, Netherlands.

Stellingen

1. De klasse II^{1} is ook niet meer wat ze geweest is.

2. Het dragen van orthodontische apparatuur heeft onbekende en ongewilde nevenwerkingen.

3. Ten behoeve van een juiste groeiprognose dienen alle kinderen die met een trauma van de kin verwezen zijn voor tandheelkundige specialistische hulp, longitudinaal gedocumenteerd te worden met schedelröntgenfoto's.

4. Arthrosis Deformans Juvenilis is niet de benaming van een bepaalde ziekte maar het op de röntgenfoto zichtbare resultaat van verschillende processen.

5. Bij het vermelden van metingen van röntgenfoto's moet de vergrotingsfactor aangegeven worden.

6. Er is technisch geen wezenlijk verschil tussen de driedimensionale meting van een gebitsmodel en die van een wulk.

   Cato ten Hallers-Tjabbes.

7. Het succes bij behandeling van kaakgewrichtsafwijking verkregen met sterk uiteenlopende therapieën, is niet zozeer een bewijs voor de juistheid van deze therapieën, als wel voor het bestaan van een groot aanpassingsvermogen van het menselijk lichaam.

8. Alhoewel de conclusies van Van Schendel *et al.* (1976) op zich juist zijn, berust het 'Vertical Long Face Syndrom' op een vergelijking van onvergelijkbare steekproeven.

9. De onvindbaarheid van een Nederlandse plaatsnaam beginnend met een X, doet vermoeden dat bij de herhaalde berisping van A. te X. in het Nederlandse Tandartsenblad steeds een andere persoon bedoeld wordt met gefingeerde initialen. Dit soort openbaarmakingen is nutteloos.

10. De kleurrijke folders, door de suikerindustrie toegestuurd aan tandartsen, zijn te beschouwen als zoethoudertjes.

11. Het streven van de Noordbelgen hun Vlaamse taaleigen te vervangen door het A.B.N. is in ieder geval ten koste gegaan van de humor in hun striplitteratuur.

12. Bij contactsporten zou het dragen van een goede gebitsbeschermer verplicht gesteld moeten worden.

13. Het verzoek waarmee menig rondschrijven eindigt om dit schrijven als niet geschreven te beschouwen is een schoolvoorbeeld van contradictio in terminis.

14. De stellingen worden veelal gelezen om een inzicht te krijgen in de persoon van de promovendus.

Stellingen behorende bij het proefschrif 'Juvenile Temporomandibular Joint Dysfunction and Craniofacial Growth' van Jos Dibbets, april 1977.

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Rijksuniversiteit te Groningen

Juvenile Temporomandibular Joint Dysfunction and Craniofacial Growth

A Statistical Analysis

Proefschrift

ter verkrijging van het doctoraat in de geneeskunde aan de Rijksuniversiteit te Groningen
op gezag van de Rector Magnificus Dr. M. J. Janssen
in het openbaar te verdedigen op woensdag 20 april 1977 des namiddags te 4 uur

door

JOSEPH MARIE HENRI DIBBETS
geboren te Weert (L)

VRB drukkerijen bv · Groningen

Promotor	Prof. Dr. G. Boering
Promotor	Prof. Dr. H. S. Duterloo
Copromotor	Dr. J. J. ten Bosch
Coreferent	L. Th. van der Weele

Paranimfen	Drs. A. K. J. Uildriks
	Drs. H. H. L. Boeije

Voorwoord

In 1968 legden G.Boering, kliniek voor Mondheelkunde, en C.Booy, kliniek voor Orthodontie, de grondslag voor een onderzoek naar de relatie tussen kaakgewrichtsafwijking, orthodontische behandeling en schedelgroei. Sindsdien hebben velen meegewerkt aan het documenteren van de kinderen uit het "kaakgewrichtsonderzoek" zoals het werd genoemd. Het is aan de enthousiaste inzet van hen te danken dat een grote hoeveelheid gegevens verzameld is. Anderen hebben bijgedragen tot de bewerking van deze gegevens en de uiteindelijke vormgeving van dit verslag.

Met name mogen worden genoemd:

Prof.Dr.G.Boering die 7 jaar leiding gaf aan een wisselend team medewerkers.

Prof.Dr.H.S.Duterloo die sterk betrokken was bij de groepering en de beschrijving van de resultaten en de totstandkoming van de Nederlandse en Engelse tekst.

Dr.J.J.ten Bosch die de aanzet voor computerbewerking begeleidde en kritische adviezen gaf bij het schrijven.

L.Th.van der Weele die de toegepaste mathematische modellen voorstelde en actief een groot aandeel had in de bewerking van het materiaal en de beoordeling van de resultaten.

Nancy Boeije–Kelley die de tekst vertaalde.

Marga van Dijken die de Nederlandse en Engelse manuscripten tot en met de drukfase verwerkte.

Else Marian Groenman die de tekeningen maakte.

Luida Noordhof die de litteratuurlijst controleerde.

Driek van Wissen die voor een uitgebalanceerde Nederlandse tekst zorgde.

Piet Kamminga die de Fortran programma's schreef en testte.

Tymen Wierstra die bij de Komplot programmatuur hielp.

Reint Steensma die de jaarlijkse controles in het ponsprotocol verzamelde.

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Jan Boersma die de tabellen controleerde.

Jan Wilmink, Jelleke Pot, Else Marian Groenman en Tsjerk de Jager die de Engelse tekst controleerden.

Drs.F.van Hoeken, drs.A.J.van der Veen, drs.A.K.J.Uildriks en drs.H.de Lange die in de loop van jaren achtereenvolgens de documentatie verzorgden.

K.J.Poel, R.J.L.Dijkstra en J.P.van Hartevelt die de zwart-wit foto's en de schedelfoto's maakten.

W.D.Lange, A.Faber en H.R.Luurtsema die de specifieke kaakgewrichtsopnamen maakten.

Bertha Clevering, Hilda Buwalda en Anneke Roggen–Veen die op verschillende manieren bij administratieve werkzaamheden hielpen.

Contents

Glossary

A (conjunction) between two variables –for example sub_0 A ob_0– means that the new variable sub_0A ob_0 has a value 1 only if the value for both components is 1. In all other cases the value is 0.

V (disjunction) between two variables –for example sub_0 V ob_0– means that the new variable sub_0 V ob_0 has a value 1 if the value for one or both components is 1. The value is only 0 if the value for both components is 0.

Contingency tables

↓ → ⇌	↓ ← ⇌
24 (47, 49, 21)	25 (41, 51, 22)
27 (53, 43, 24)	36 (59, 57 32)

The figure in front of the parentheses in the contingency tables is the absolute number. That is, the sum of these four numbers must equal 112 (children investigated).
The first figure within the parentheses is the percentage reflecting the fraction of the column total, indicated by ↓. The column total is always 100%.
The second figure within the parentheses is the percentage reflecting the fraction of the row total, indicated by → or ←. The row total is always 100%.
The third figure within the parentheses, indicated by ⇌, is the percentage of all the children. Because the figures have been rounded off, the sum of these percentages does not always equal 100%.

Chapter 1

Introduction

1.1 Craniofacial growth and the mandibular condyle

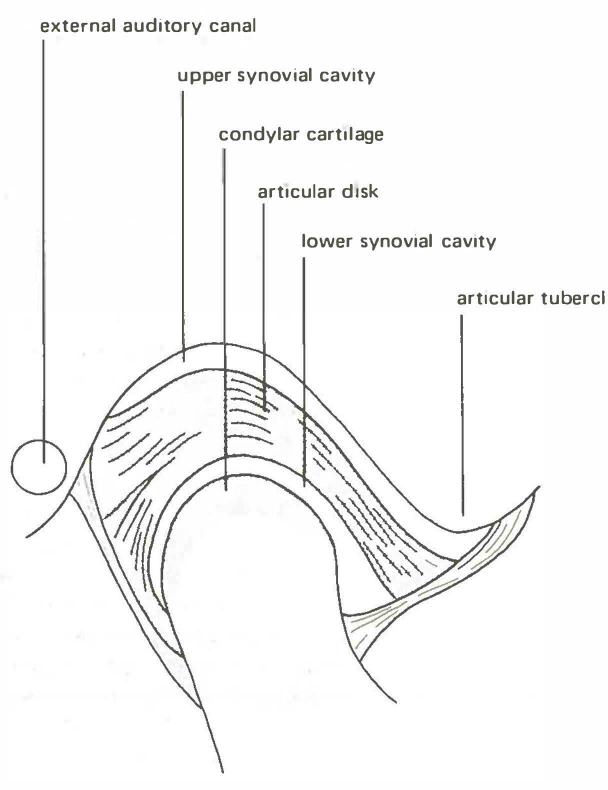
The rapidly increasing body of knowledge about the growth and development of the craniofacial skeletal structures has clearly begun to influence clinical dentistry. The study of craniofacial growth has been intensified and expanded in the last twenty years in particular. As a result greater insight into the fundamental aspects of craniofacial growth and development has been obtained, and equally if not more important, the systematic investigation of craniofacial deformities has made a start. Methods have also been developed to influence the growth of the craniofacial skeleton.

The mandibular condyle appears to fulfill an important function in the extremely complex craniofacial growth process. Both the function fulfilled and the nature of the growth regulation mechanisms involved have been subjects on which controversial opinions have been formed. Also, certain forms of orthodontic therapy aim to influence condylar growth. Extensive literature exists about syndromes of the temporomandibular joint which are referred to in this study as temporomandibular joint dysfunction.
Until now, the relationship between craniofacial growth and development on the one hand, and temporomandibular joint dysfunction on the other has received very little attention. A better insight into this material would contribute to an increased understanding of the etiology of temporomandibular joint dysfunction as well as to an improvement of differential diagnosis and therapy.

For a proper understanding of the processes of craniofacial growth, currently used terminology is introduced. Bone forms in two ways: by **intermembranous** or **endochondral** ossification. In intramembranous bone formation, the mesenchymal cells differentiate directly into osteoblasts and begin ossification. During endochondral bone formation, the mesenchymal cells first become chondrocytes and form cartilage. Cartilage cells hypertrophy and their matrix becomes calcified, erodes and bone is formed on the remains of the matrix. Growing bones are involved in a **remodeling** process of **apposition** and **resorption**. This remodeling process results in **relocation** which is when the position of a portion of bone changes in relation to its borders. **Drift** is when two portions of an individual bone become reoriented to one another; **displacement** is (passive) transference of a bone in relation to other bones (Enlow 1975[1]).
Various theories have been developed about the regulation mechanisms which are responsible for an harmonious progression of these complex processes in the growing skull; the new theories are based in part on insights gained from the older ones. The most important theoretical contributions in this area come from Sicher (1945), Sicher and DuBrul (1952), Scott (1954, 1956, 1967), Moss (1962, 1972[2]) and Van Limborgh (1970, 1972).

The mandible is a composite of endochondral and intramembranous bone formation: endochondral growth in the condylar region occurs in conjunction with intramembranous ossification in corpus and ramus. In recent years in particular, much research has been done concerning the way in which this ossification is regulated: among others, Epker and Frost (1966), Justus and Luft (1970), Chamay and Tschantz (1972) and Theunissen (1973) have been active in this area.
Temporomandibular joint development differs radically from the development of other joints. The morphology and function of this development are also very different. For brevity's sake, the reader is directed toward the schematization in Figure 1.1, and to the literature (Brodie 1939; Weinmann and Sicher 1947; Symons 1952; Baume 1962; Moffet 1965; Yuodelis

Figure 1.1 Schematic cross section of the temporomandibular joint.



1966[1], 1966[2]; Bloom and Fawcett 1968; Derksen 1971; Durkin 1973; Cran 1976).

Conceptions of the mode and importance of condylar growth are highly divergent. Among others Brodie (1941), Boman (1952) and Moffet *et al.* (1964) have made general, descriptive studies of the condylar adaptations which they have observed. Thilander (1976) divides those studying the role of the condyle in craniofacial growth into two groups: the classicists, who regard the condyle as a primary growth center (Sarnat 1957; Baume 1968, 1970, among others) and the modernists, who ascribe a more adaptive role to the condyle (Moss 1962; Duterloo 1967; Koski 1968; Van Limborgh 1970 among others).
Many experiments have been done with animals to discover methods for influencing the temporomandibular joint. In spite of the fact that conditions can be more precisely controlled and more specific methods can be applied in such experiments, interpretations of results often prove to be contradictory. Several investigators believe that the condyle and the position of the joint are very difficult to influence (Hiniker and Ramfjord 1966; Ramfjord and Hiniker 1966; Meikle 1970; Payne 1971). However, most investigators are convinced that condylar growth can definitely be influenced (Breitner 1930, 1940; Charlier *et al.* 1959; Baume and Derichsweiler 1961; Folke and Stallard 1966; Charlier and Petrovic 1967; Lemoine *et al.* 1968; Charlier *et al.* 1969; Stöckli and Willert 1971; McNamara jr. 1972, 1975; Petrovic *et al.* 1974, 1975).

Experiments using human material must use entirely different methods. Older, established aids are dental casts originally combined with photographs, later with cephalograms. The introduction of the X-ray cephalostat (Broadbent 1931) was an important step toward greater sophistication in measurement. Subsequent to this development, standardized radiographs could be made of the head. This made longitudinal studies possible; at the same time, a strong need was felt for reliable registration points for measurement or the construction of reference planes. "The Workshop on Cephalometrics" was inaugurated in the U.S.A. in 1957 to explore the conflicting opinions concerning the value of the various uses to which cephalograms, and particularly superpositioning could be put. A second report was released in 1960 which introduced a standard nomenclature (Salzmann 1960).

Superpositioning of cephalograms can be done in two ways: total superpositioning on stable structures of the cranial base, and local superpositioning on stable structures of one of the bones composing the skull. Total superpositioning deepens understanding of the skull in its entirety, local superpositioning of an individual bone. The current technique of total superposition is based primarily on the results of an investigation by Melsen (1974) using human autopsy material. Application of the metal implant technique in humans by Björk has made it possible to construct an accurate local superposition of the mandible. The individual mandibular growth pattern can be precisely determined by superpositioning the cephalogram on the image of the metal implants. Björk has observed and classified different types of mandibular growth rotations, and has indicated new, relatively stable areas on which structural superposition is possible (Björk 1955, 1963, 1969).

The advent of tracings and computations which can be controlled and carried out by the computer was a further development which led to the publication of Riolo *et al.* (1974), and Broadbent *et al.* (1975). These atlases contain tables with means and other data of diverse parameters measured longitudinally in growing individuals.

A most recent development is that advanced computer techniques make possible the application of predesigned, sophisticated statistical procedures (statistical package). Such procedures are available on permanent file at many scientific computer centers (Van der Weele 1976, 1977). These techniques were used in the present investigation.

1.2 Temporomandibular joint dysfunction

Temporomandibular joint dysfunction has been discussed extensively in the literature. Some authors approach the aspects of description, etiology and diagnosis from multiple angles and disciplines (Schwartz 1959; Sarnat 1964; Boering 1966). Others reduce the problem to a specific area in dentistry and discuss only one or several of its aspects.
The entire area of dysfunction has been only vaguely defined (Lindblom 1953; Freese 1958[1], 1958[2]; Lindblom 1960, 1971; Laskin 1969; Lupton 1969; Bell 1969; Loiselle 1969; De Boever 1973; Molin *et al.* 1976; Shore 1976; Yemm 1976; Rugh and Solberg 1976).
A number of different names have been given to syndromes which display only minimal differences from one another. This multiplicity of designations immediately points to one of the largest problems which exists in this area. This is the lack of understanding of the relationships of the symptoms with one another. Some authors have attempted to meet these objections. Mayne and Hatch (1969) distinguishes five types of symptoms; Speck and Zarb (1976), however, use a classification system, McCall *et al.* (1976) make objective measurements and Helkimo (1976) has designed an index. These categorizations assume that the symptoms considered belong to the same syndrome, or have the same cause, without systematically investigating or proving that this is so.

Steenks (1976) warns against names which implicitly connect the temporomandibular joint to an etiology without explicity demonstrating the relationship between pathology of the temporomandibular joint and the symptom.

The multiplicity of symptoms described in the literature can be subsumed under three main headings:
a. Visible deformations on X-ray's.
b. Subjective symptoms revealed by the patient.
c. Objective symptoms, determined by the clinician himself.

Radiographs of the temporomandibular joint have been described by Boering (1966) and Worth (1974). Figures 1.2 and 1.3 show Parma radiographs of healthy joints. In contrast, clearly deformed contours are visible in Figures 1.4 and 1.5. Descriptions of visible transformations and their longitudinal effects have been given by Boering (1966, 1976[1], 1976[2]), Ericson and Lundberg (1967), Rönning *et al.* (1974) and Odenrick (1976), among others. Engel *et al.* (1949) and Blackwood (1963) believe that the temporomandibular joint is the first joint to be affected by rheumatism. Boering (1966) contradicts this in his investigation.
Subjective and objective symptoms are often recognized as such, but are seen as different expressions of the same phenomenon. Blackwood (1963) postulates that crepitation of the joint is the only observable symptom of temporomandibular joint dysfunction between the ages of twelve to twenty-five years. King (1963) suggests that crepitation is usually reversible.

The therapies which are suggested and applied vary widely. The most drastic treatment is condylectomy (Poswillo 1972, 1974), the most simple the prescription of rest and warmth. Blair already reported in 1930 that a rehabilitation of the masticatory function appeared after a condylectomy. The result of such an intervention perhaps explains the success which many clinicians report with different types of therapy. An inconceivably large number of compensations can apparently ensure a reasonably satisfactory functioning.

1.3 Statement of problem: objectives of this investigation

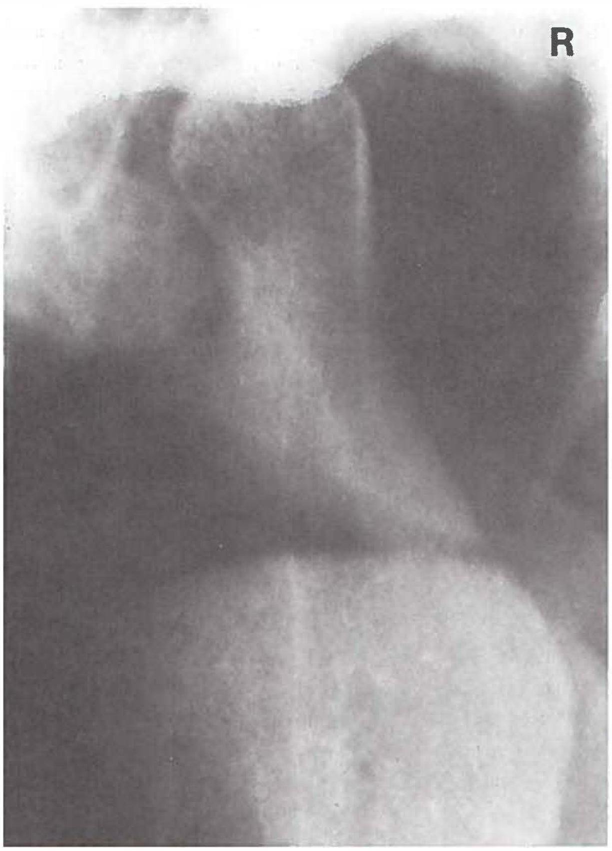
A number of investigators have tried to demonstrate the influence of orthodontic treatment on the growth of the mandibular condyle (Baume *et al.* 1959; Derichsweiler 1966; Domec 1967; Müller and Herren 1971; Demisch 1973). These authors assume that the condyles from their material were healthy and that a slumbering growth potential can be mobilized. When the proliferation of cartilage in the condyle is disturbed as the result of temporomandibular joint dysfunction, then this anticipated condylar response will either fail to develop or will occur to a lesser degree. This is very important for the results which can be expected from orthodontic therapy. If it is realized that a pathological deformity of the temporomandibular joint exists, then orthodontic treatment could also be a possible predisposing factor. Since the diagnosis and treatment of pathological disturbances of the temporomandibular joint is normally carried out by the oral surgeon, a team approach involving two departments was decided upon: Oral Surgery and Orthodontics. There was a major advantage attached to this choice: The Department of Oral Surgery could carry out the diagnostic aspect of the temporomandibular joint dysfunction investigation autonomously, while the documentation for a longitudinal study could be assembled by the Department of Orthodontics.

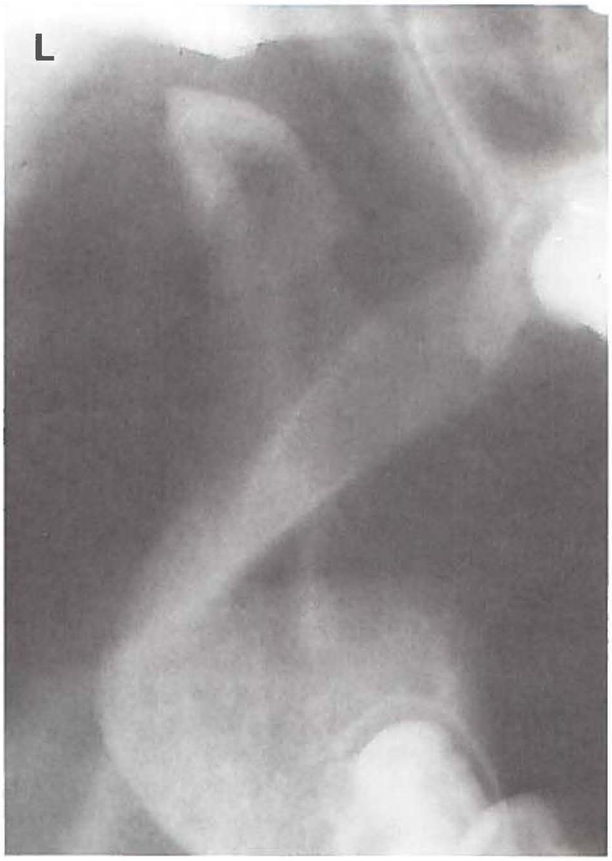
The demarcation of the area covered by temporomandibular joint dysfunction is vague. For the present study, the X-factor temporomandibular joint dysfunction is built up from three different components. These are subjective symptoms -revealed by the child-, objective symptoms -determined by the investigators-, and deformations of the condyle visible on the X-ray. This last category of deviations has been defined as **Arthrosis Deformans Juvenilis**, ADJ.

Three questions underly this investigation:
a. What is temporomandibular joint dysfunction?
b. Does a mandible become enlarged following the moment at which deformations of the condyle -ADJ- are ascertained?
c. Does orthodontic therapy cause ADJ?
The first question concerns the relationship between temporomandibular joint dysfunction and craniofacial structure. In the two other questions, temporomandibular joint dysfunction is limited to those deformations which are visible on the radiograph. It will be attempted to describe the relationships of a number of symptoms to one another with the total material -data obtained from 112 children with an Angle class II, division 1 malocclusion. The effect of these relationships on craniofacial growth will be explored, without, in that exploration, adding a new meaning to the numerous ones which already exist for temporomandibular joint dysfunction.
In answering the first question, analytical statistical methods have been used. During this statistical phase, there was close cooperation with the Project Group for Statistical Application of the Computer Center of the University of Groningen. The methods are briefly described in Chapter 4; the definitions of the variables and the different symptoms are given in Chapter 3.
The second question can be answered by using radiographs of the temporomandibular joint and cephalograms on which the size of the mandible can be measured.
The third question can only be approached indirectly;

Figures 1.2 and 1.3 Parma radiographs of healthy condyles.

Figures 1.4 and 1.5 Parma radiographs of deformed condyles.





the data from all the X-ray's are needed for that analysis.
In Chapters 5, 6 and 7 are described the effect and occurrence of temporomandibular joint dysfunction. The symptoms are analysed separately in Chapters 8 and 9, and a synthesis follows in Chapter 10. Chapter 11 contains information which can be applied in dental practice.

Chapter 2

Material and Methods

2.1 Material

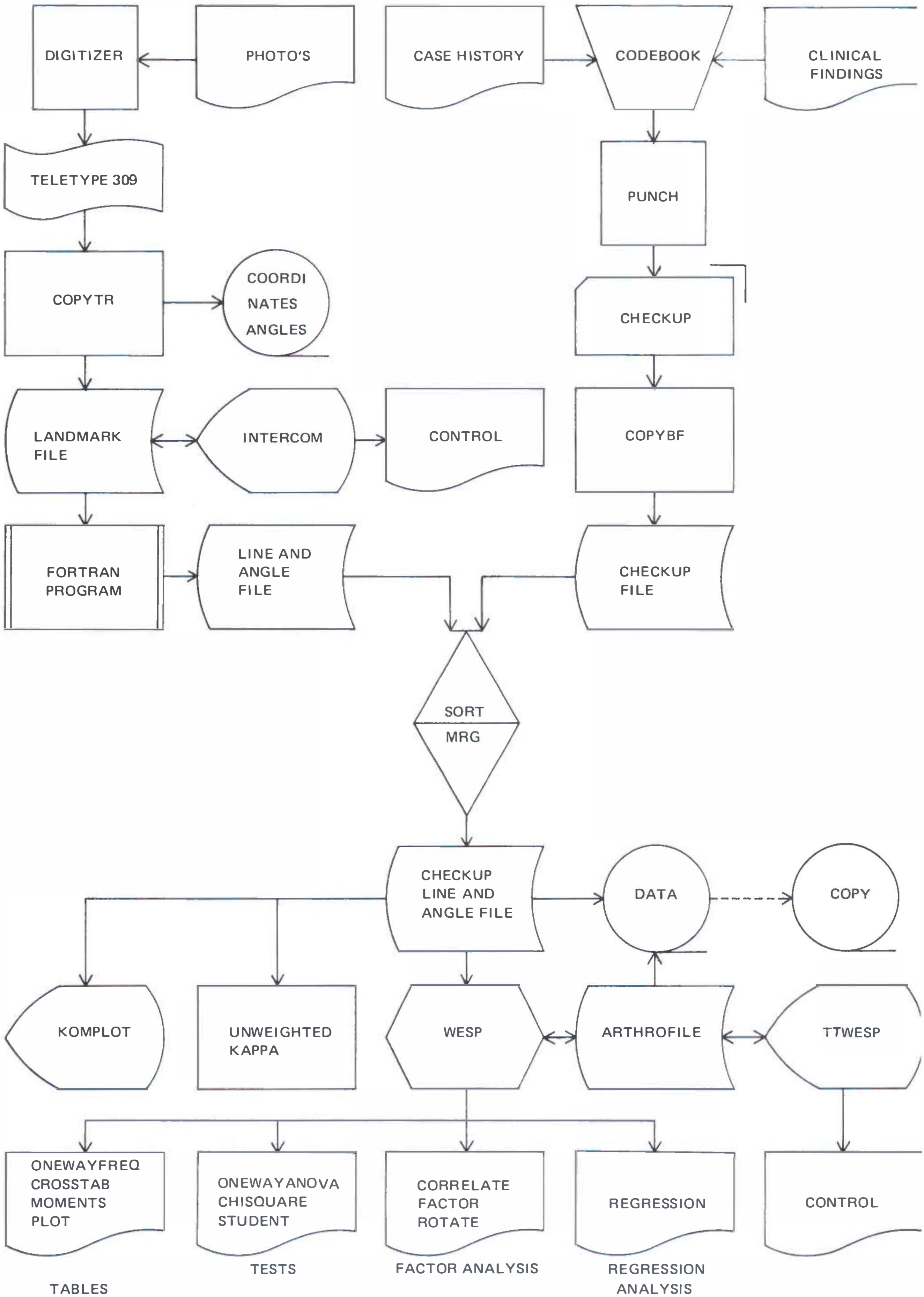
2.1.1 Introduction

The composition of the group of children investigated, and detailed information about the means of data collection are presented in this chapter. A systematic case history and various types of X-rays and photographs have been used to assemble the data. The photographs are used as a source of measurements, or they are evaluated according to morphological and structural criteria. All the data is processed by using specially developed computer programs to make them amenable to statistical manipulation. A flow chart (Figure 2.1) gives a schematic representation of this computer and statistical manipulation. The definition of the variables and the choice of methods of statistical analysis are treated in Chapters 3 and 4.

One hundred twelve children –forty–nine boys and sixty–three girls– were involved in the study. Their mean age at the outset was twelve years and six months. The youngest was eight years and six months old; the oldest was seventeen years and three months. The investigation was conducted over a six year time space; during this period the children were examined and completely documented at least four times at intervals of twelve months.

The children were selected in the following manner:
- They were referred to the Department of Orthodontics of the University of Groningen by their family dentist for consultation or treatment of an orthodontic malocclusion; they were accepted for treatment in the period from September 1969 to and including June 1972.
- They had to exhibit an orthodontic class II, division 1 malocclusion according to the Angle classification, and had to be undergoing treatment with functional or fixed appliance.
- The teeth had to be well maintained, with adequate oral hygiene and the subjects had to have the proper age to qualify for immediate orthodontic treatment.
- Only healthy children were considered eligible; that is, neither the case history nor the preliminary examination should have indicated the presence of any congenital defects, or of any obvious pathology in the orofacial region.

Figure 2.1 Flow chart (ISO).



From the 139 children originally considered, the following 17 were not included in this investigation for a number of general reasons:
five turned up less than four times for examination and/or treatment;
five were older than seventeen years and six months at the outset;
two proved to be insufficiently documented;
two underwent a modification of the orthodontic therapy;
three were found to have a general retardation of growth
Ten more children were dropped from the study for more specific reasons, which will be elucidated later in this chapter. Data from 112 children were finally available for processing.

All the children were fully documented and examined for temporomandibular joint dysfunction before the orthodontic treatment was begun.
The material is divided into groups according to which research goal is being considered. The children were treated with activator or Begg appliance with class II elastics. This also produced a division into two groups. **In this study the beginning age is defined as being the age at the moment that the activator or the fixed appliance is installed; this moment is likewise considered to be the date of the first control (year 0).**

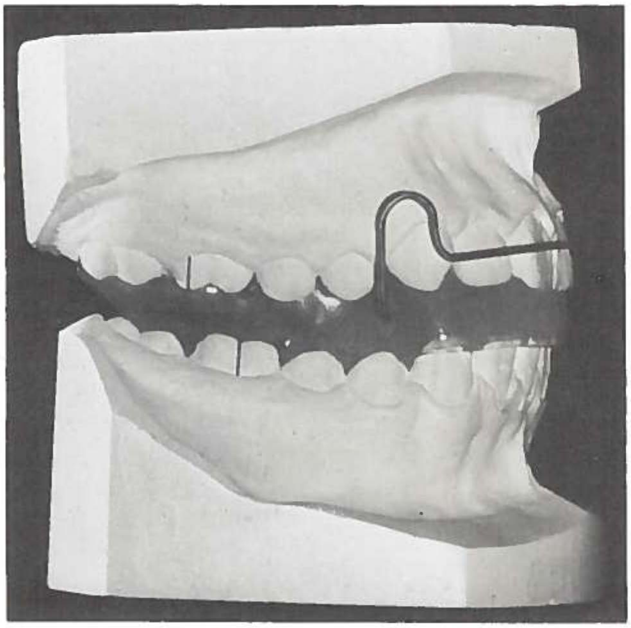
2.1.2 The group with activator

The activator was first described by Andresen and Häupl (1936); much has been published about it since, especially in Europe (Petrik 1940[1], 1940[2], 1942, 1952; Björk 1951; Eschler 1952; Andresen *et al.* 1953; Herren 1953, 1956; Schwarz 1961; Hausser 1963; Freunthaller 1963; Demisch 1973; Harvold and Vargerik 1971; Harvold 1974).

The activator is a massive acrylic block into which the lower and upper dental arches fit. When the child's jaws close, the mandible is forced into a more advantageous relationship than it had normally. The prime purpose of the therapy is to evoke new reflexes in the neuromusculature of the masticatory system. This type of treatment occupies a place apart in orthodontic therapy. Opinions are divided as to exactly how the observed changes in the occlusal relations come about. A discussion of these disagreements is beyond the scope of this study.

The activator fitted on the children in the study is modified according to Booy (1958), and is characterized by:
- a large sagittal and vertical step;
- considerable extension of the lingual wings;
- capping of the lower front teeth;
- an anterior labial section (0.9 mm) from 13 to 23, extending from the acrylic in the middle interocclusal region;
- interdental extensions (when necessary) mesial from 16, 26, 36 and 46;
- no clasps around teeth; as few screws and auxilliary springs as possible.

Figure 2.2 Activator on a dental cast, as it is fitted in the orthodontic laboratory. Note the sagittal step and the vertical opening.



Children with a class II, division 1 profile, with a distocclusion, and with an excessive overjet qualified for treatment with an activator. There had to be no rotation of the teeth, and the lower arch had to have a good shape. The child had to be young enough so that a reasonable contribution from facial growth could be expected. Because no auxilliary springs were fitted, it was necessary in some cases to give a preliminary therapy before the activator treatment could be begun. This preliminary therapy employed removables in all cases, and was usually preceded by the extraction of two premolars in both the lower and upper jaws. A total of thirteen children from the group under study was preliminarily treated in this manner. The average fourteen months required for this treatment was not reckoned as part of the investigation. Possible diastemata were always closed while the activator was being fitted.

An additional ten children were eliminated from the investigation for reasons other than the general ones presented in 2.1.1:

- eight children, because their cooperation was in doubt. This was 15% of the group with activator.
- two children, because during the activator treatment it became evident that two premolars would have to be extracted.

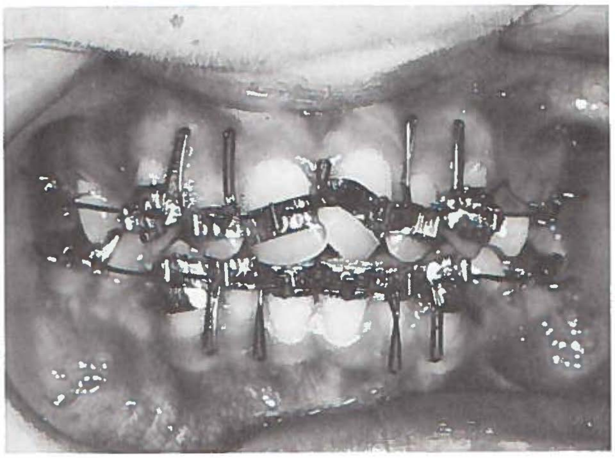
Figure 2.3 Activator which has not yet been trimmed. Note the anterior labial section, interdental extensions mesial from the molars, the deep lingual wings and the capping of the lower front teeth.

Fifty-one children, twenty-seven girls and twenty-four boys, finally met all the requirements. The mean age at the outset of the investigation was eleven years and four month for both boys and girls. The activator treatment lasted eighteen months on the average for the girls and twenty-two months for the boys. The results of the treatment were generally satisfactory, with for example, the achievement of a class I molar occlusion with incisal contact.

2.1.3 The group with Begg appliance with class II elastics.

The Begg appliance was developed by Begg in Australia (1954, 1956, 1961); extensive descriptions can be found in Begg and Kessling (1971), Graber and Swain (1975) and Booy (1963, 1965, 1966, 1967, 1968, 1970, 1971), among others.

Figure 2.4 Begg; Stage I.



During Begg treatment, stainless steel bands are fitted onto each tooth, with a bracket attached to each band. An hardened stainless steel wire is attached to all the brackets, thus connecting all the teeth of the dental arch. A full discussion of this apparatus is likewise beyond the scope of this investigation; further reference to this topic can be found in the bibliography. Children with an Angle class II, division 1 malocclusion qualified for treatment with the Begg appliance. The permanent teeth were almost complete, therefore the mean age in this group was somewhat higher than that in the group with activator. The Begg appliance was chosen because the malocclusion was severe (rotations, position of the cuspids, and usually, the inevitability of extractions). At the beginning of the treatment, four premolars were extracted from 90% of these children. In seventy-five percent of the cases the teeth extracted were 14, 24, 34 and 44; in fifteen percent they were 15, 25, 35 and 45. Ten percent of the children were treated nonextraction. Preliminary treatment was not deemed necessary for any of the children.

No children needed to be eliminated from the group under study except those excluded earlier for general reasons as explained in 2.1.1. Cooperation was consistently good. At the conclusion of the treatment there was a consistent class I molar and cuspid occlusion, good interdigitation, and incisal contact with slight overbite in every case.

The group with Begg appliance consisted of sixty-one children, thirty-six girls and twenty-five boys. The mean age at the outset of the study was thirteen years and seven months for the girls, and thirteen years and ten months for the boys. Active

treatment lasted an average nineteen months for the girls and twenty-one months for the boys.
A removable retainer was worn on the upper jaw for several months following the treatment, usually only at night.

2.2 Documentation

2.2.1 Introduction

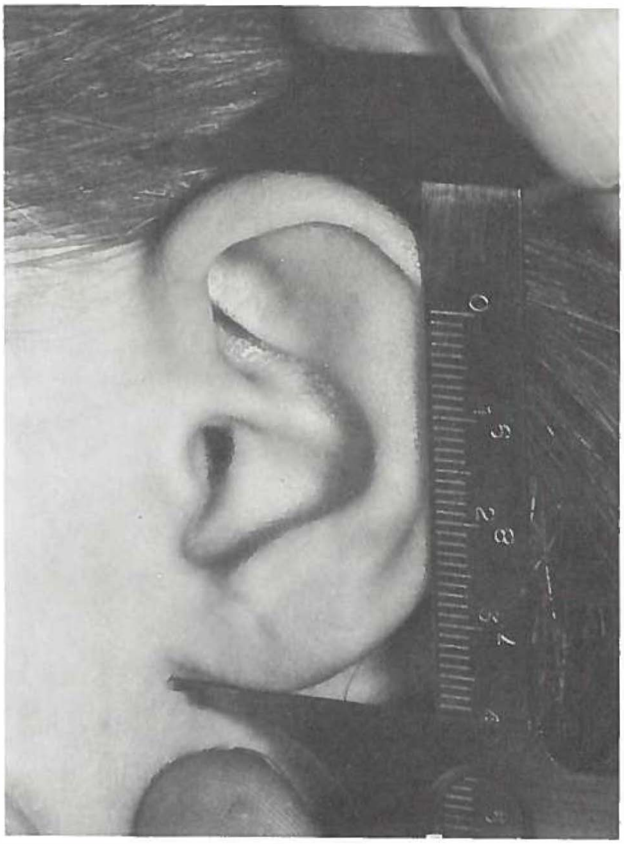
Each child was examined once a year at both the Department of Orthodontics and the Department of Oral Surgery, apart from the frequent visits for examination and checkups connected with the orthodontic treatment. Each of these two departments had a specific contribution, both in the clinical examinations and in making and interpreting X-rays, in order to safeguard the objectivity of the data as much as possible. The source of data for the Department of Orthodontics were the cephalogram, the orthopantomogram, the black and white photographs and clinical examination; the Department of Oral Surgery contributed the temporomandibular joint radiographs according to Parma and according to Schüller and clinical examination.
The Schüller radiographs (1912) proved in retrospect to be extremely difficult to translate into digital information and were therefore not used further in the study.

2.2.2 Case history and clinical findings

Department of Orthodontics

In composing the case history at the Department of Orthodontics considerable attention was devoted to factors which might indicate general disturbance of growth, or to factors which might function as indicators of such disorders such as rheumatism, pediatric ailment, hospital admissions and use of medicines. Whenever there were definite indications of a disturbance, the child was eliminated from the investigation (2.1.1). Attention was paid to oral habits such as gnashing and clenching of teeth, thumb- or finger-sucking, and nail-biting. Subjects were consistently questioned about possible trauma of the chin; the examining orthodontist also checked under the chin for the presence of a scar that might possibly provide evidence of a trauma suffered in the past. There were no children with diagnosed fractures of the jaws. The children were questioned specifically at every checkup about the whole range of complaints which can possibly occur as a result of changes in the temporomandibular joint.
Both temporomandibular joints were palpated during the clinical examination, while the child was directed to open and close the mouth as completely as possible. The course of the open-close cycle and the mobility in all directions were both assessed. The vertical length of the auricle (Figure 2.5) was measured yearly with a vernier caliper from the upmost edge to the lowest point of the ear lobe. The maximal mouth opening between the central incisors of the upper and lower front was measured, likewise by using a vernier caliper.

Figure 2.5 Measuring the vertical length of the auricle with a verniers calipers.

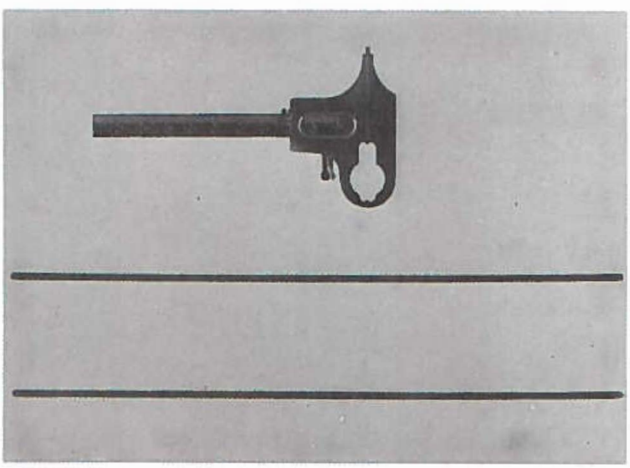


The possible existence of a forced bite was investigated, the face was examined from a frontal view for asymmetry. Possible deviation of the chin and of the interlabial line were factors to be considered in this connection. The transverse slope of the occlusal plane and the height of the gonial notches were estimated by using copper bars (Figures 2.11 and 2.12).

Department of Oral Surgery

The examination conducted at the Department of Oral Surgery was virtually identical to the one performed at the Department of Orthodontics. The stage reached in the development of the permanent dentition, the presence and the location of diastemata and attrition (an indication of unconscious gnashing of teeth), the correspondence of the midline of upper and lower arches, and differences in masticatory capacity (forced one-sided mastication) between the left and right sides were all likewise noted. These last-mentioned differences were classified as left larger than right or the reverse, and were attributed to the number of buccal teeth.
If the findings at the Department of Oral Surgery disagreed with those of Orthodontics, the investigators tried to trace the causes of these differences. Discrepancies of more than 0.5 mm in measurements were not tolerated; rejected measurements were carried out again, until agreement was reached.

Figure 2.6 Boley verniers calipers with verniers for reading in 0.1 mm and copper bars used during the clinical examination. Note the centimetre division on one bar.



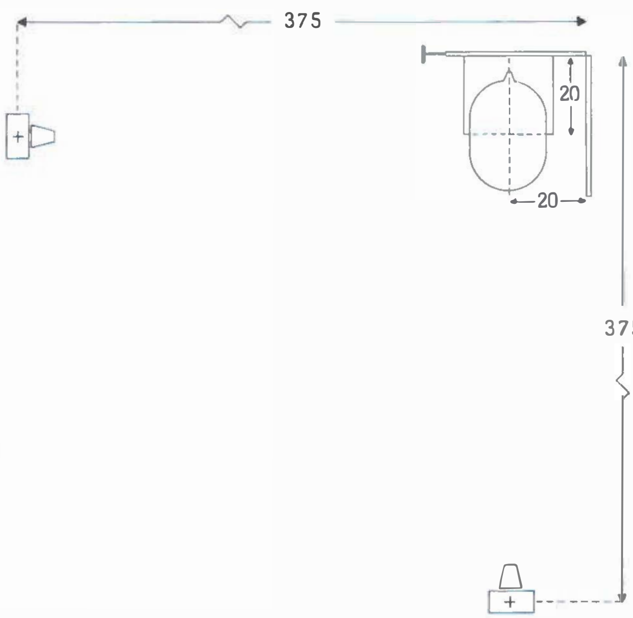
2.2.3 X-rays

A lateral and frontal cephalogram, an orthopantomogram, and radiographs according to Parma of the left and right temporomandibular joints were made of each child yearly.

Lateral and frontal cephalograms

The cephalograms were made according to a standardized method, using an X-ray cephalostat in which the child's head is fixed in a manner which can be exactly duplicated. This cephalostat was constructed from a 1950 design of K.G.Bijlstra, and has been discussed by Van der Linden (1959).
A change in the apparatus was made in July 1970, which made it necessary to apply a correction factor of 1.022 to measurements of cephalograms made before that date.
The cephalograms were made as follows:
- focus-film distance: 375 cm, for both lateral and frontal radiographs (Figure 2.7).
- exposure an average of 1 second with 95 kV, 250 mA.
- Frankforter horizontal of the child set up parallel to the upper and lower edge of the film.

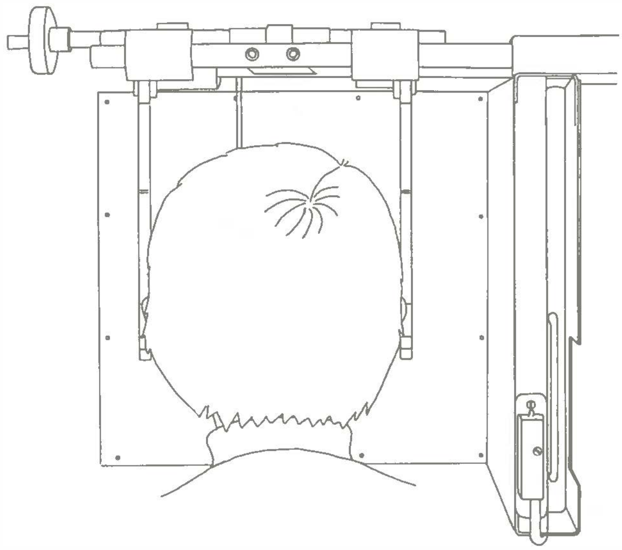
Figure 2.7 Fixed position used in Groningen for making frontal and lateral cephalograms. Measurements are given in centimetres.



The earrods used to fix the head in position could both be moved simultaneously and at an identical distance in opposite directions perpendicular to the median plane. This assured that the median plane of the head was always at a fixed distance of 20 cm from the film (Figure 2.8).

In making the radiographs, care had to be taken that the child's bite was in centric occlusion. Because a setup was used in which two X-ray tubes were used, together with a cephalostat in which two films were placed perpendicular to each other (Figures 2.9 and 2.10), the lateral and frontal cephalograms could be made simultaneously.

Figure 2.8 Child in the cephalostat. The earrods fix the median plane of the head at an identical distance 20 cm from both films.



Orthopantomogram

The orthopantomogram was made with a Palomex OY Orthopantomograph, according to the Paatero principle (1954). The child was required to bite end to end. The mean exposure time was 13 seconds with 55 kV, 50 mA.

Parma radiographs of right and left joints

The specific infra-cranial contact radiograph according to Parma (1932), made with the mouth maximally opened produces an excellent image of the condyle and of its position in relation to the articular tubercle. The exposures were made with a 55 kV Oralix from which the cone was removed with an exposure time of 0.35 seconds.

2.2.4 Photographs

Photographs en face were taken yearly in order to

Figure 2.9 Cephalostat, view for the frontal cephalogram. The pointer P is placed on the left (skin) Orbitale.

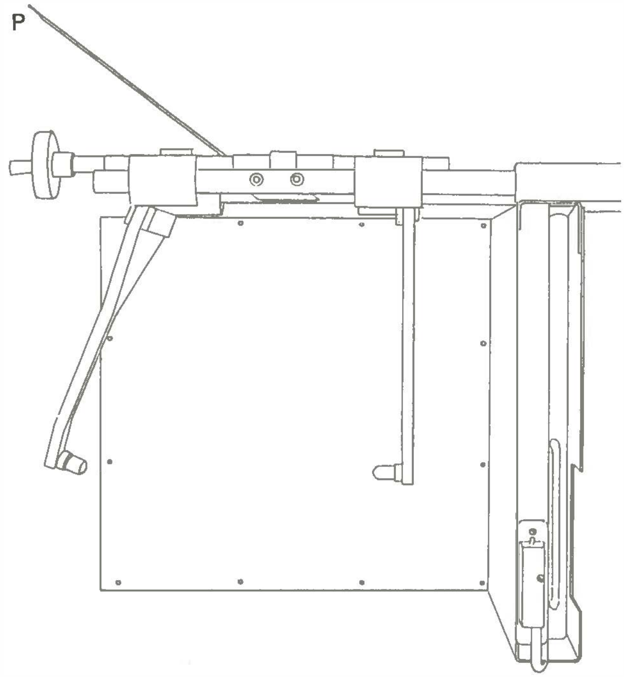
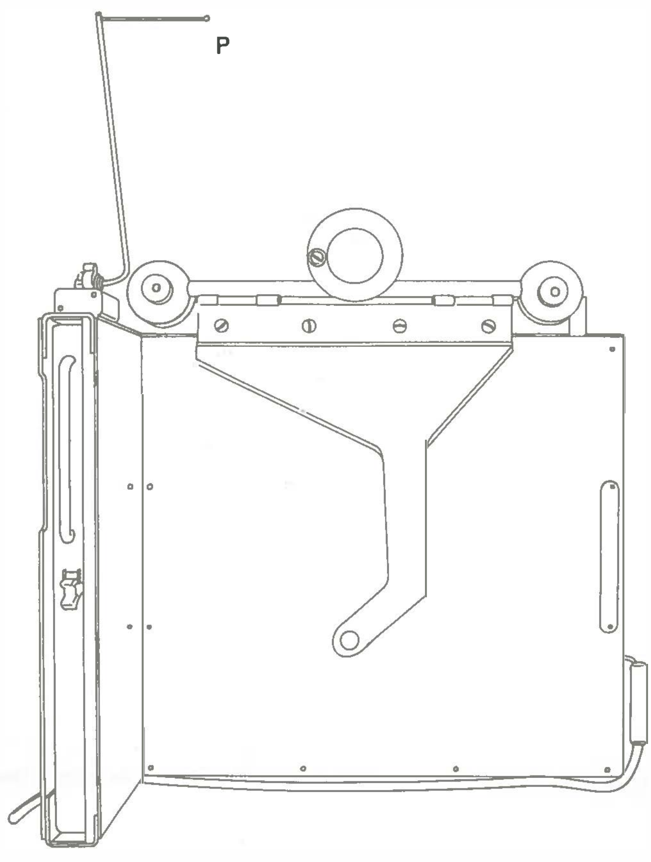


Figure 2.10 Cephalostat, view for the lateral cephalogram. The pointer P is placed on the left (skin) Orbitale.



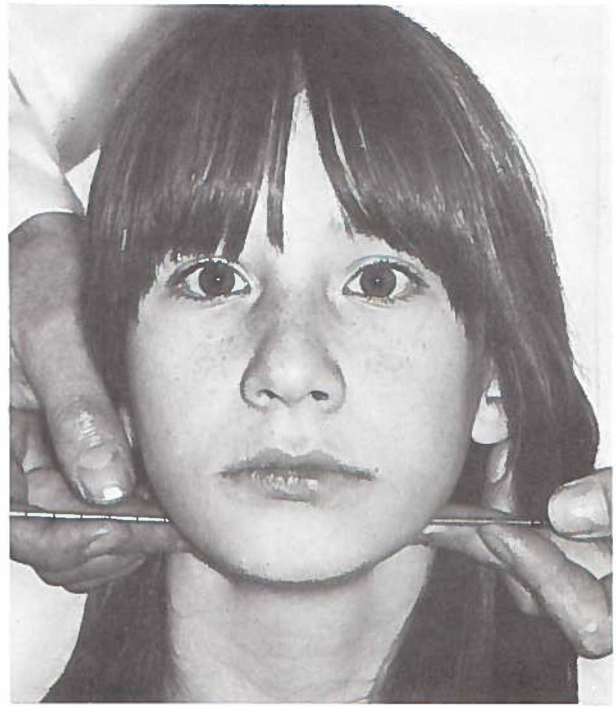
document the development of asymmetries of the face. The same copper bars were used in making the photographs as those employed in the extra-oral examination. The child sat in a relaxed position while the picture was being taken, with his head in the Frankforter horizontal. The distance between the camera and the face was always 125 cm. A centimeter division on one of the bars was used as a control measure for making prints of the photos at actual head size.

A picture of an interocclusal bar was taken to determine the transverse slope of the occlusal plane. Two corresponding points in the upper jaw (usually the buccal groove from 16 and 26) were selected, and a round copper bar 250 mm long and 3 mm in diameter was pressed against them. This was fixed by having the child bite on it, and then a determination was made whether or not good contact was maintained between the bar and the upper jaw (Figure 2.11).

Figure 2.11 Photograph used to determine the transversal slope of the Occlusal Plane.

The two copper bars were placed firmly against the skin of the lower jaw at the highest point of the gonial notch (Antegonion), and they were adjusted until they were horizontal to the camera. This photograph was used to determine eventual differences in the levels of the two gonial notches (Figure 2.12).

Figure 2.12 Photograph used to determine different levels of the gonial notches.



2.3 Frequency of observations

The children were examined immediately before the start of orthodontic treatment and were subsequently examined every twelve months, apart from appointments with the orthodontist. They were all documented four times, most of them five times. The examination conducted by the Department of Oral Surgery always took place at the most fourteen days after the orthodontic examination. The orthodontic treatment of all the children was completed by the fourth visit.

2.4 Adaptation of documentary material

2.4.1 Introduction

The adaptation of the raw data consisted of two stages. First, the assembled data were adapted for use in a computer. The coordinates of the photographs and cephalograms were used in a FORTRAN computer program in which angles and distances were calculated

(Organick and Meissner 1974). The data from the lateral and frontal cephalograms were sometimes combined in making these calculations. Second, the data were statistically analysed to discover correlations among the various variables.

2.4.2 Case history and clinical findings

The data of case histories and the data from the clinical observations of the Department of Orthodontics and Oral Surgery were translated into computer language according to a codebook. The 548 case histories and clinical data provided by Orthodontics were combined in this manner with the case histories and data from Oral Surgery. One hundred forty-one variables were extracted from the data for further analysis.
The course of the entire procedure is sketched in Figure 2.1.
The data were transferred into punch cards and subsequently to a computer disk (Figure 2.1, upper right). The information on the punch card, together with the calculations obtained from the lateral and frontal cephalograms and photographs, were transferred to a tape. This tape consequently contained about 100.000 bits of information. These calculations from cephalograms and photographs had been recorded per child in punch card code (Figure 2.1, upper left). This concluded the first stage of the data adaptation.

WESP (1976) was used for the statistical operations; this is a statistical package developed at the Computer Center of the University of Groningen (chairman, D.W.Smits, Ph.D.). The operations were carried out on a Control Data Cyber 74-16 computer.
The WESP program was put to several of its potential uses to check the boundaries of the measurement data (READDATA). Landmarks which had not been clearly identifiable when working with the coordinate digitizer and relegated to "infinite" in a FORTRAN program were replaced by missing data (NEWMISDAT). Numerical scatter diagrams were made with the printer (PLOT), so that data which deviated radically from the mean values could be traced. Controls were applied to check whether or not the programming of the data had proceeded correctly, for example by repeating the direct measurement of photographs and radiographs.

2.4.3 X-ray's

Lateral cephalogram

The commonly accepted cephalometric landmarks, distances, planes and angles, as defined in orthodontic literature (Krogman and Sassouni 1957; Yen 1960; Salzmann 1960), formed the basis for the measurement of distances and angles on the lateral cephalogram.
These landmarks and planes are shown in Figure 2.13; Table 2.1 presents a list of the landmarks and planes.

The cephalograms were measured on a coordinate digitizer built at the Central Institute for Industrial Research, Oslo, Norway; the operations were carried out at the Department of Orthodontics of the University of Amsterdam (chairman, Professor N.Myrberg, D.D.S., Ph.D.).
This coordinate digitizing equipment consists of cross wires which are suspended above an X-ray illuminator in such a way that both a point and a direction can be determined. The points are recorded in 0.1 millimeters, the angles in 0.1 degrees. This information is automatically typed out on an online Teletype 309 and punched into an one-inch paper tape according to the eight-hole ASCII code.
In order to determine the landmarks on the X-ray, a frosted acetate overlay measuring 0.01x20x25 cm was placed over the first cephalogram. Subsequently, the cranial base was traced and Sella was indicated. Basion and Nasion were marked, and Pogonion was constructed. It was determined whether or not Nasion and Basion had been properly chosen, using the then following cephalograms of that series as a control. These cephalograms were superimposed as exactly as possible on the anterior cranial base. Measurements were carried out directly upon the cephalogram. Exceptions to this rule were Sella, which was superimposed; Basion and Nasion from the first cephalogram, which were traced; and Pogonion from all the cephalograms, which was constructed.
In a number of cases a landmark could not be

Figure 2.13 Cephalometric landmarks and planes which were measured directly from the cephalogram.

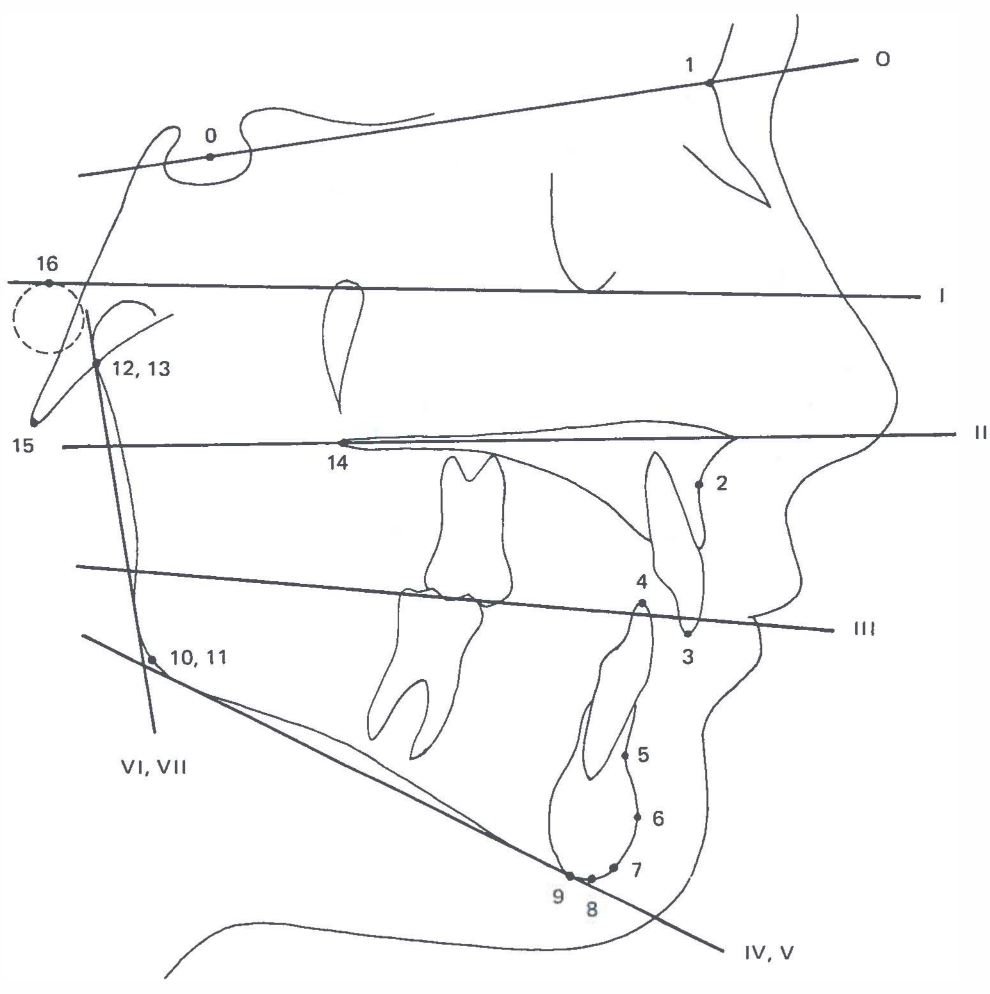


Table 2.1 List of cephalometric landmarks and planes which were measured directly from the lateral cephalogram. Figure 2.13.

Number	Code	Definition
0	S	The estimated middle of Sella Turcica.
1	N	Nasion – Riolo *et al*., 1974.
2	A	A – Downs.
3	UIE	Upper Incisal Edge – Riolo *et al*., 1974.
4	LIE	Lower Incisal Edge – Riolo *et al*., 1974.
5	B	B – Downs.
6	Pg	Pogonion – Riolo *et al*., 1974.
7	Gn	Gnathion – the point most distant from Sella on the bony chin symphysis.
8	Me	Menton – the point most distant from the line S-N on the contour of the bony chin symphysis.
9	9	junction of the lower border and symphyseal outline of the mandible.
10, 11	Go	Gonion – the estimated midpoint of the angle of the mandible.
12, 13	Ar	Articulare – Riolo *et al*., 1974.
14	PNS	Posterior Nasal Spine – Riolo *et al*., 1974.
15	Ba	Basion – Riolo *et al*., 1974.
16	Po	Porion – Riolo *et al*., 1974.

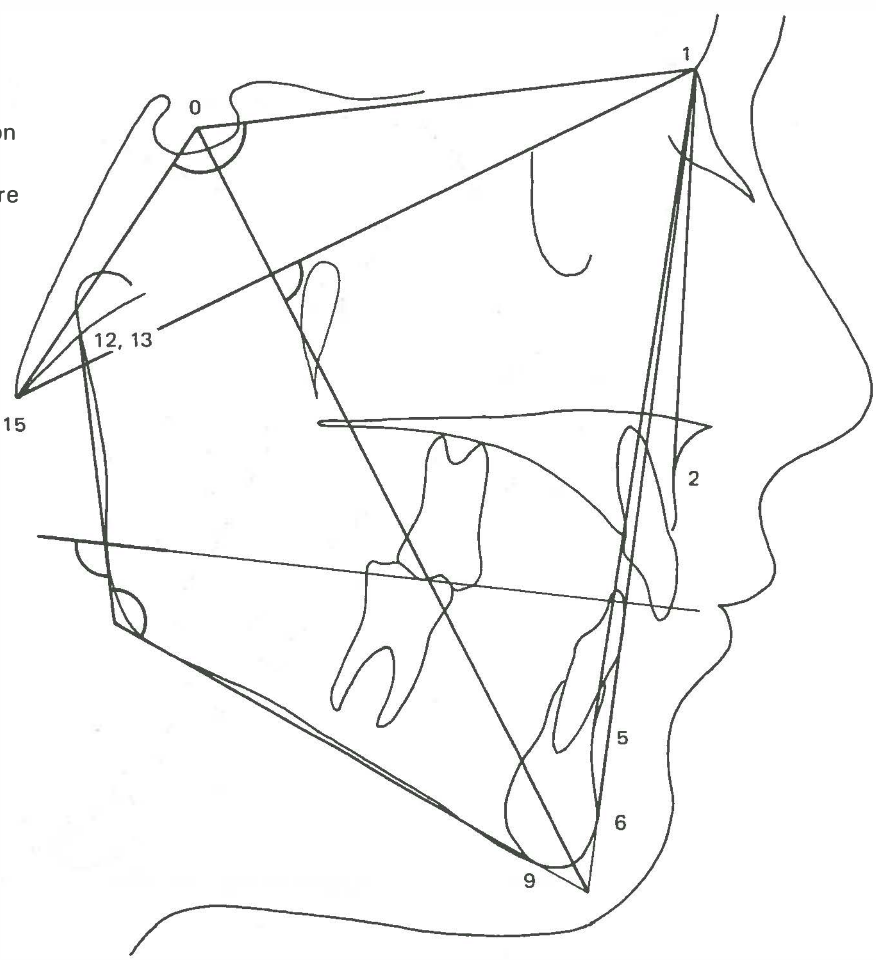
Plane	Code	Definition	Defining landmark
0	S-N	Sella-Nasion	0,1
I	FH	Frankfort Horizontal	16
II	PP	Palatal Plane	14
III	OP	Occlusal Plane	3,4
IV, V	MP	Mandibular Plane $_{l,\ r}$	9
VI, VII	RP	Ramal Plane $_{l,\ r}$	12, 13

Table 2.2 List of the derived angles used in the analysis of the lateral cephalogram. Figure 2.14.

Angle	Determined by
Gonial angle $_{l,\ r}$	IV-VI and V-VIII.
∠ RP/OP $_{l,\ r}$	III-VI and III-VII.
∠ S-N-Pg	0–1–6
∠ S-N-B	0–1–5
∠ S-N-A	0–1–2
∠ Ba-S-N	15–0–1
Y-axis $_{l,\ r}$	Angle between a line from S (0) to the intersection of N-Pg with MP, and the line Ba-N. One MP has been defined for right and one for left, so there is also an Y-axis for left and right.

Figure 2.14 Angles derived from the original landmarks and planes. Table 2.2.

0	Sella
1	Nasion
2	A
5	8
6	Pogonion
15	Basion
12,13	Articulare



determined because the structure was vague, or because a landmark did not exist according to the definition given. The coordinate digitizer was then raised 5 cm or more above the Sella–Nasion line, so that a coordinate pair was created which could be identified later as missing data. This was necessary because the absence of one landmark would otherwise cause the computer to reject data from the entire cephalogram.

Five hundred forty-eight lateral cephalograms were measured according to the procedure outlined above. Seventeen cephalometric landmarks and seven angles were determined for each cephalogram. Forty-six variables were abstracted from this data for further investigation. The landmarks and planes are listed in Table 2.1, the derived dimensions in Tables 2.2 to and including 2.4. The latter are pictured in Figures 2.13 to and including 2.17.

The angle between the planes I to and including VII and Sella–Nasion was measured directly from the cephalogram. All these planes were later laid through their defining cephalometric landmarks by using a FORTRAN "lines and angles" program. In this way the relationship between these planes was fixed.

Frontal cephalogram

The frontal cephalograms were handled in the same way as the lateral ones. Five hundred forty-eight frontal cephalograms were measured. Thirteen points and one angle were determined for each cephalogram. A total of twenty variables was derived from these data and used in further analysis.

Figure 2.15 Linear dimensions derived from the original landmarks. Table 2.3.

0	Sella
1	Nasion
6	Pogonion
7	Gnathion
12,13	Articulare
15	Basion

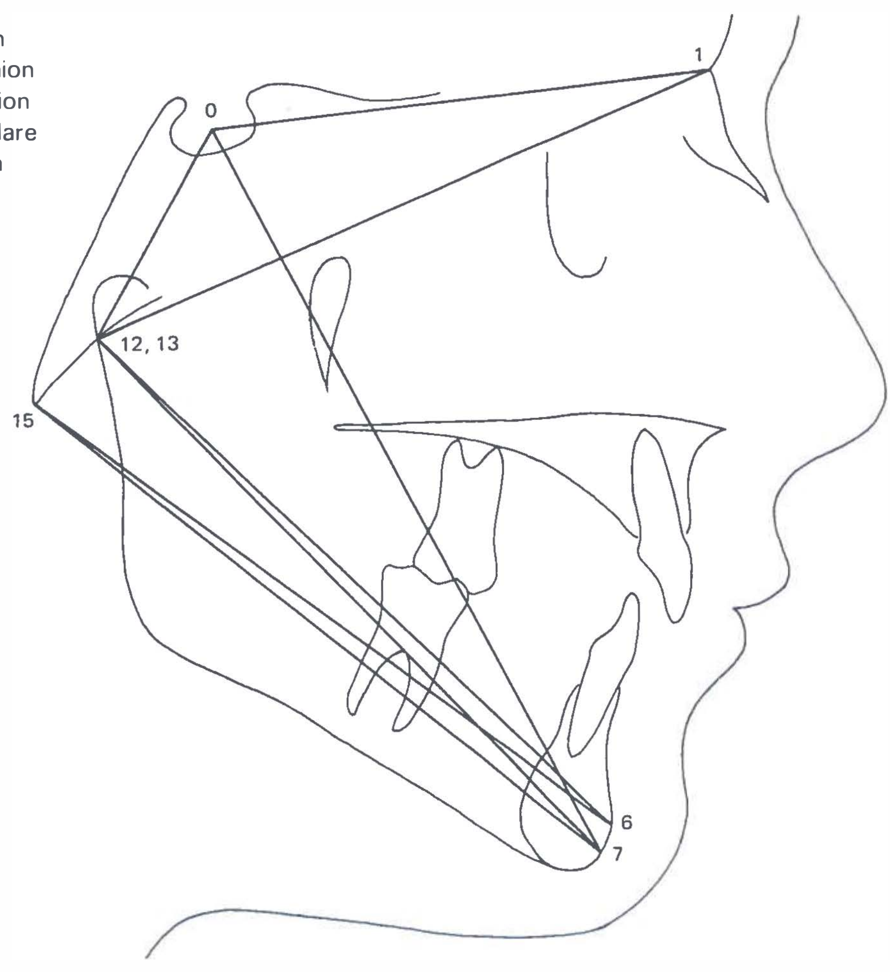


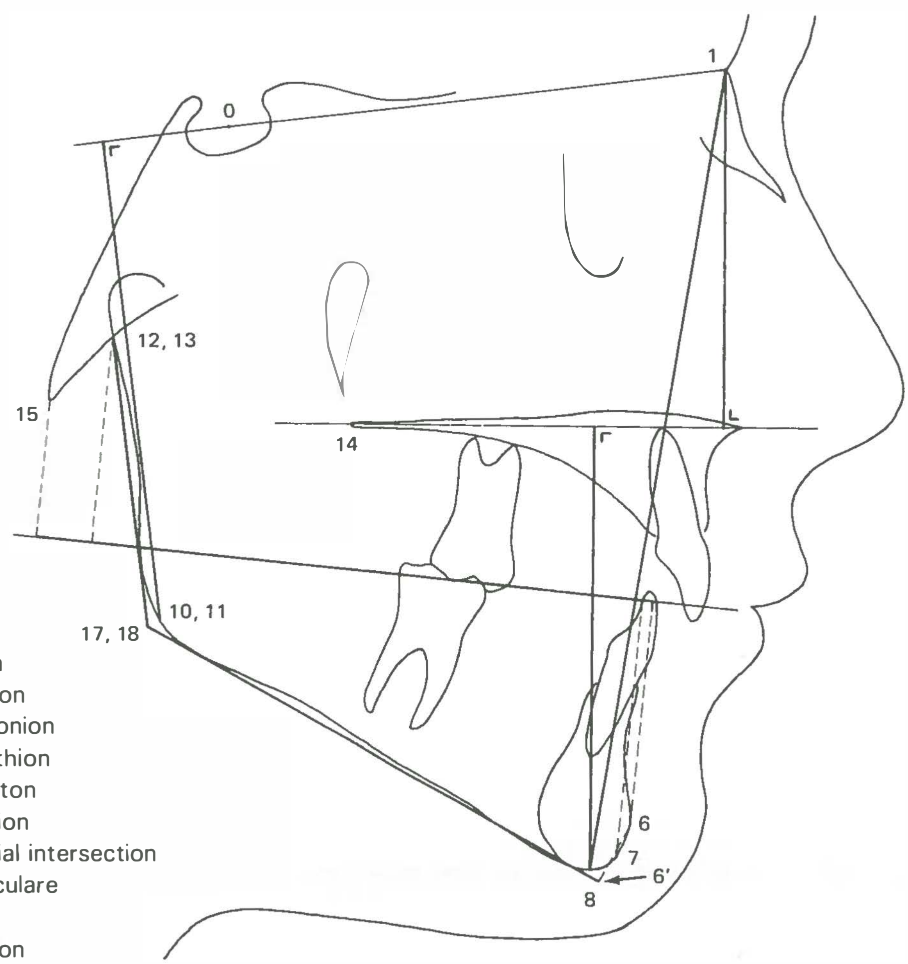
Table 2.3 List of computed linear dimensions used in the analysis of the lateral cephalogram. Figure 2.15.

Linear dimension	Determined by
TFH	1–8
UFH (Figure 2.16)	The Upper Face Height is determined by the length of the projection from Nasion (1) on the Palatal Plane.
LFH (Figure 2.16)	The Lower Face Height is determined by the length of the projection from Menton (8) on the Palatal Plane.
PFH (Figure 2.16)	The Posterior Face Height is defined by the length of the projection from Gonion (10, 11) on Sella-Nasion.
S-N	0–1
S-Ar $_{l,\,r}$	0–12, 0–13
Ar-N $_{l,\,r}$	12–1, 13–1
S-Gn	0–7
Ar-Gn $_{l,\,r}$	12–7, 13–7
Ar-Pg $_{l,\,r}$	12–6, 13–6
Ba-Gn	15–7
Ba-Pg	15–6
Gol $_l$-Gol $_r$	Gol is the intersection of IV and VI or V and VII.

Table 2.4 List of some of the computed projections used in the analysis of the lateral cephalogram. Figure 2.16

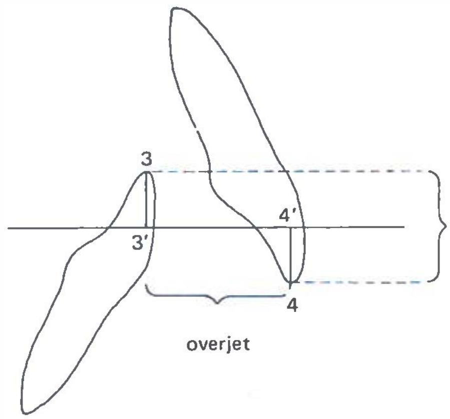
Projection	Determined by
Overjet (Figure 2.17)	The overjet is determined by projecting the upper and lower incisal edges on the Occlusal Plane.
Overbite (Figure 2.17)	The overbite is determined by computing the sum of the lengths of the projections of the upper and lower incisal edges on the Occlusal Plane.
Ar-Gol $_{l,\,r}$	The distance from Articulare to Gonial Intersection is used as a mesure of the height of the ramus.
Gol-Pg $_{l,\,r}$	The distance from the projection of Pogonion on the Mandibular Plane, Pg', to Gol is used as a measure of the length of the corpus.
Pr Ba-Pg	Projection on the Occlusal Plane.
Pr Ar-Pg $_{l,\,r}$	Projection on the Occlusal Plane.
Pr Ba-Gn	Projection on the Occlusal Plane.
Pr Ar-Gn $_{l,\,r}$	Projection on the Occlusal Plane.

Figure 2.16 Projections computed from the original landmarks and planes. Table 2.4.



0	Sella
1	Nasion
6	Pogonion
7	Gnathion
8	Menton
10,11	Gonion
17,18	Gonial intersection
12,13	Articulare
14	PNS
15	Basion

Figure 2.17 Overjet and overbite. Table 2.4. 3–3'=4–4'



A line passing through the intersection of the lateral part of the orbit with the squamosal part of the temporal bone on the right and left sides was defined as the direction, and the intersection on the right side was defined as the origin.
The landmarks and one angle are shown in Table 2.5, the derived landmarks in Table 2.6. The landmarks are illustrated in Figures 2.18 and 2.19.

Table 2.5 List of cephalometric landmarks and one angle measured directly on the frontal cephalogram. Figure 2.18.

Number	Definition
100, 102	The intersection of the projection of the squamosal part of the temporal bone (*Linea innominata*) with the lateral part of the orbit.
101	The projection of the Crista galli on the line 100–102.
103, 111	The lowest point of the mastoid of the temporal bone.
104, 110	Gonial notch, left and right. The deepest point in the curvature anterior to the gonial angle.
105, 112	The intersection of the extension of the lower border of the zygoma and the lateral projection of the alveolar process of the maxilla, left and right.
113	The computed midpoint of a line through the mandible at the height of Gnathion.
106	A point in the midline of the upper dental arch.
107	A point in the midline of the lower dental arch.
–	Angle formed by the lower edge of the cephalogram with a line through 100–102.

Table 2.6 List of derived angular and linear dimensions used in the analysis of the frontal cephalograms.

- line through 100–102: the base line.
- angle 110–104 with the base line (plane through gonial notches).
- angle 111–103 with the base line (plane through mastoids).
- angle 112–105 with the base line (plane through zygomas).
- distance from the origin (100) to the projection of Crista galli on the base line.
- distance from the origin (100) to the projection of the mid-line of the upper dental arch on the base line.
- distance from the origin (100) to the projection of the mid-line of the lower dental arch on the base line.
- distance from the origin (100) to the projection of the midpoint of the chin (113) on the base line.
- distance from the origin (100) to the projection of the midpoint of the gonial notches (110–104) on the base line.
- distance from the origin (100) to the projection from the midpoint of the mastoid (111–103) on the base line.
- distance from the origin (100) to the projection of the midpoint of the zygoma (112–105) on the base line.
- the length of the projection from left and right gonial notches (110–104) on the base line.
- the length of the projection of left and right mastoid (111–103) on the base line.
- the length of the projection of left and right zygoma (112–106) on the base line.
- the distance from the midpoint of the chin (113) to the best fit through the points 100, 101, 102, 111, 103, 112 and 105. Figure 2.19.
- the distance between the midpoint of the gonial notches (110–104) to the best fit through the points 100, 101, 102, 111, 103, 112 and 105. Figure 2.19.
- the distance from the midpoint of the gonial notches (110–104) to a perpendicular from the midpoint on the base line.
- the distance from the projection of the midpoint of the chin (113) on the base line to projection of the midpoint of the gonial notches (110–104) on this line (100–102).

Assignment of cephalometric landmarks to the left or right side

It was necessary to decide which structural contours on the lateral cephalogram belong to the left and which to the right side of the skull. The decision was reached by using data from the simultaneously–taken lateral and frontal cephalograms, the standardized values of the distances between focus, object and film as previously discussed, and from a left–right decoding program written in FORTRAN (Figure 2.20).

In the röntgencephalostat in Groningen, the central beams for both the frontal and lateral exposures are perpendicular to each other, and their paths form a horizontal plane. The flat side of the cassettes holding the film to be exposed are directed perpendicularly to the beam, while the lower edge runs exactly parallel to this plane through both beams. The films in these cassettes have just enough room to ensure a flat position and a good junction with the bottom of the cassette. The short frontal cephalogram edge is therefore parallel to the central beam for the lateral cephalogram; the same is true for the lateral cephalogram.

The distance between the earrod and the middle of the gonial angle on the lateral cephalogram (distance from 16 to the middle of 10 and 11) represents the distance A–A' from the middle of the gonial notch on the frontal cephalogram (104 and 110) to the central beam (Figure 2.13). The angle of incidence E of the X-ray beam through A' in relation to the lower edge of the cephalogram is computed from the relationship between A–A' and A–focus (here 375–20=355 cm).
E=Arctan(A–A'):3550.
Angle D is the computed angle between the line connecting the gonial notches and the lower edge of the cephalogram.
When the difference F between these two angles is computed, the following relationships hold:

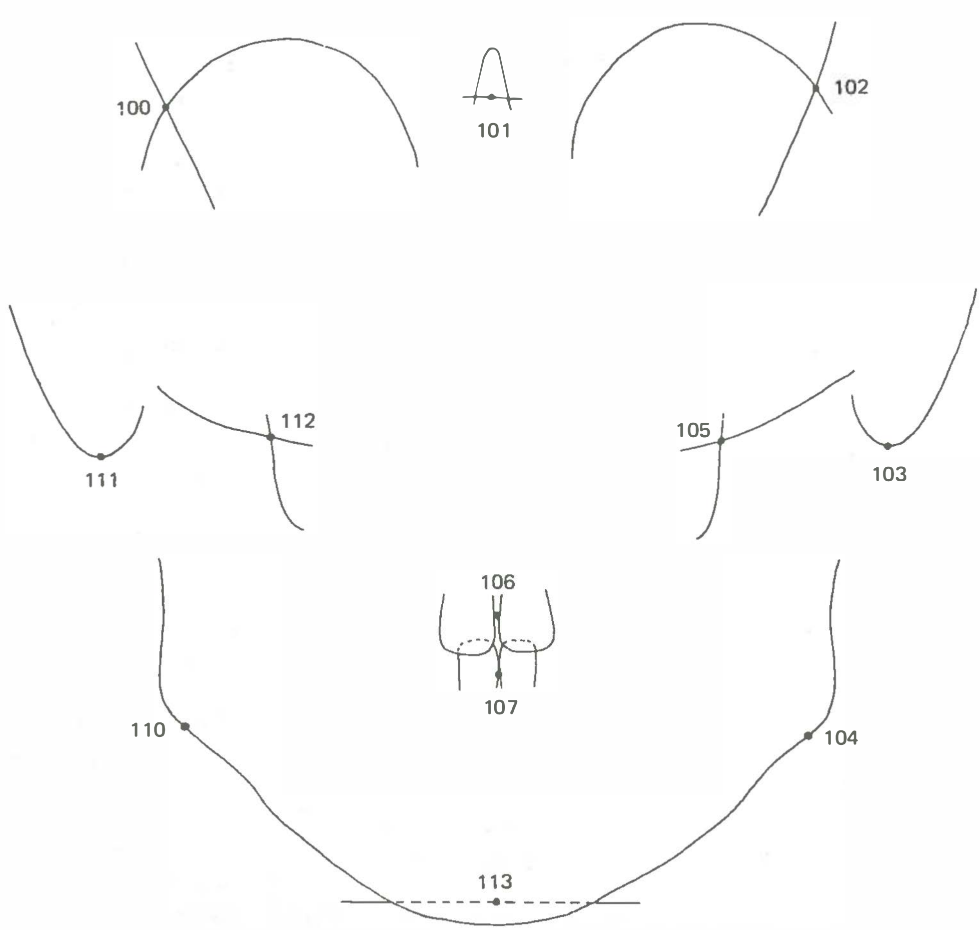
F=D–E
F>0: left projection of the corpus on the lateral cephalogram is above the right projection.
F<0: right projection of the corpus on the lateral cephalogram is above the left projection.
F=0: left and right Corpus project on top of each other.

Whenever a choice had to be made while digitizing landmarks and angles from the lateral cephalogram, the values belonging to the lowest projection of the mandible were consistently measured first. This made possible a systematic decoding of the left and right projections; special correction factors were later applied for both sides (section 2.5.2).

Orthopantomogram (OPG)

The OPG is used to divide the study into groups displaying the same stage of dentitional development. The calcification stage of the teeth 37 to and including

Figure 2.18 Cephalometric landmarks on the frontal cephalogram Tables 2.5 and 2.6



31, minus 34, are scored according to a scale introduced by Nolla (1960). The 34 was not scored because in several cases it had already been extracted before the exposure was made.

Figure 2.19 Distance from midpoint Gonions and midpoint chin to the best fit through 100, 101, 102, 111, 103, 112 and 105. Table 2.6.

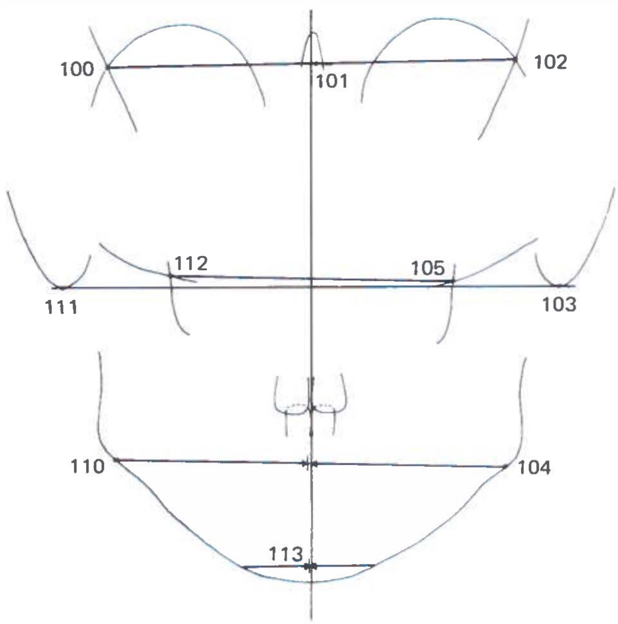
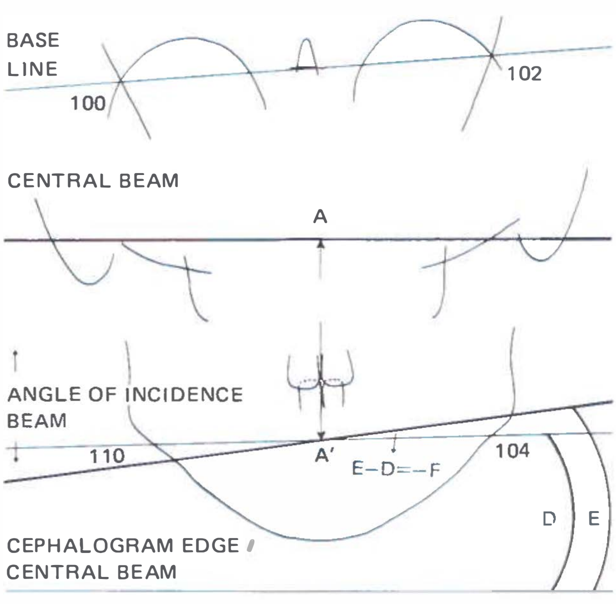


Figure 2.20 Left–Right decoder using the frontal cephalogram.



According to Liliequist and Lundberg (1971), the score from one mandibular half exhibits a significant correlation with the skeletal age. These scores therefore were sometimes used in an attempt to obtain a division according to identical skeletal age.

Parma radiographs of left and right joints

The Parma radiographs were used to diagnose morphological or structural changes of the mandibular condyle and the articular tubercle. Projections of the left and right joints were systematically compared to accomplish this purpose. Parma radiographs were also used to make objective determinations of maximum mobility of the mandible.
Definite deformities like those which will be described shortly, were recorded; morphological deformities usually consisted of flattening of the anterosuperior portion of the contour of the condyle. This was defined as left or right flattened. The joint was classified as hypermobile if the condyle was situated on the anterior side of the highest point of the articular tubercle when the mouth is maximally opened.

The projection of the condyle of a normal joint has a smooth convex contour. Because the condyle is wider transversally than sagittally, when the X-ray beam falls somewhat too far forward a part of this wider aspect is projected anteriorly on the condyle, producing an image which is more oval than usual; the condyle can then even appear flattened. The primary spongiosa of the normal condyle is homogeneous in structure and the trabeculae are perpendicular to the surface.
The normal image of the articular tubercle also has a smooth, convex contour. It is usually impossible to recognize here any clear orientation in the primary spongiosa.
If no deformation can be observed on the radiograph, then a conclusion cannot validly be reached that such a deformation does not exist. The contrast, for example, may not be sharp enough, or a rehabilitation may have provided for a (temporarily) normal image. Moreover, no cartilage can be distinguished on X-rays.
If changes are evident on the radiograph due to deforming osteoarthritis, they can be divided into deformations in an active phase and deformations in a passive phase.

In the active phase small clarifications under the contour of the condyle are sometimes seen on the radiograph. The image sometimes appears "cystic". The contour is rough, eroded and displays gaps with frayed edges. The rather sharp border usually present becomes blurred. The structure of the primary spongiosa can no longer be seen. Assessment of consecutive projections reveals the degeneration process apparently to be one of progression toward flattening.
The deformation in the passive phase can be seen as a flattening of the condyle and sometimes as a

dorsoflexion of the condyle ("head in the neck"). There is a reduction of the dimension in the sagittal direction, for instance of the diagonal Condylion–Pogonion, marginal hypertrophy can occur, and there is sometimes an (apparent) extension of the longest dimension of the condyle. The primary spongiosa lacks a definite orientation. According to literature the mobility of the joint is limited (Boering 1966).

At the end of the entire research period, 1096 Parma radiographs were again sorted per child and –this time anonymously– assessed by two experienced investigators for the presence of deformities. An attempt was made to make a diagnosis from the radiograph. This is more fully discussed in section 3.2.1.
The final evaluation as transposed into the codebook, was reached by combining the yearly assessment of the Parma radiograph with the results of the "blind" judgement. When a deformity was ascertained by one of these two evaluations, then ADJ (Arthrosis Deformans Juvenilis, i.e. juvenile deforming osteoarthritis) was scored into the codebook for the year in question.

2.4.4 Photographs

The photographs were also plotted with the coordinate digitizer; a line through the reflections of the flash in the pupils was fixed as the direction, and the right pupil as the origin. Two photographs en face per child per year, or a total of 1096, were measured in this manner. Six points and two angles were determined for the two combined photos. This data yielded a total of seven variables used later in various analyses.
The angle formed by the intersection of the line drawn through the two pupils with the interocclusal bar, and with the interlabial line, were measured.
The cephalometric landmarks and derived landmarks are shown in Table 2.7 and are pictured in Figures 2.21 and 2.22.

Table 2.7 List of landmarks and measured or derived angular and linear dimensions used in the analysis of the photographs. Figures 2.21 and 2.22.

Number	Definition
200	reflection of the flash in the right pupil.
201	reflection of the flash in the left pupil.
202	midpoint of the nose (estimated).
203, 205	gonial notch, represented by a copper bar which is placed firmly in a horizontal plane at the corresponding soft tissue point, right and left.
204	midpoint of chin (estimated).
–	distance from the projection of the midpoint of the nose on the line through the two pupils (200–201) to the origin (200).
–	the same as the midpoint of the chin.
–	the same as the midpoint of the gonial notches (203, 205).
–	the length of the projection from 203 and 205 on the line through the pupils (200–201).

Figure 2.21 Determination of the transversal slope of the Occlusal Plane by using a photograph. Table 2.7.

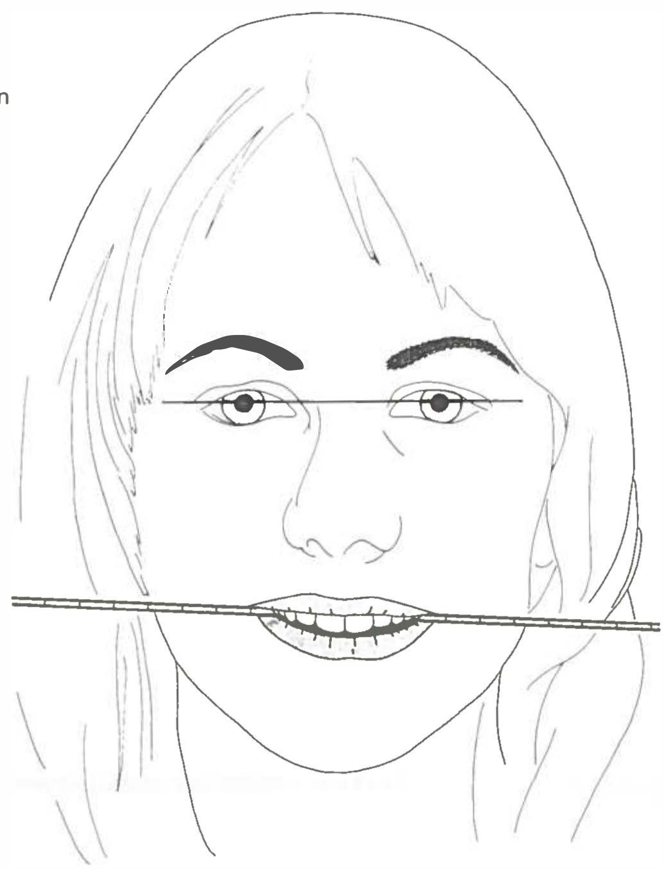


Figure 2.22 Landmarks and slope of interlabial line on the photograph. Table 2.7.

2.5 Errors of measurements

2.5.1 Introduction

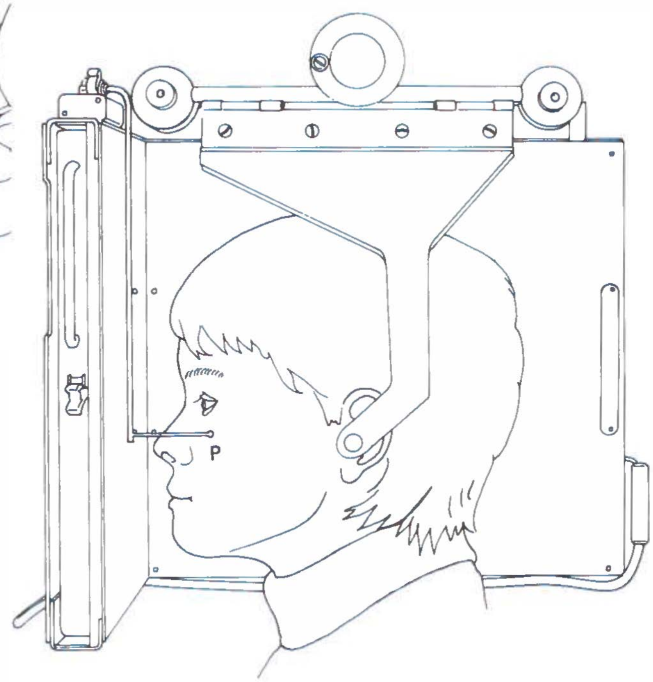
There are two types of factors which can influence the results obtained from measurement of X-rays and photographs; errors in making them, and errors made in measuring them.
For both types there are two kinds of deviations that need to be considered, namely:
- a systematic error; this is inherent to the measurement system followed and usually deviates in one direction. A good example of this sort of error is measuring with a shortened ruler;
- a random error; this usually deviates in both directions (normal distribution).

2.5.2 Lateral and frontal cephalograms

Errors in making the cephalogram

The most important systematic error is the magnification which occurs because the skull is projected from a focal source. This magnification will occur to the same degree with every exposure, and is dependent upon the relationship of the distances focus–object–film to one another. The right side of the child was always turned toward the cassette in this investigation (Figure 2.23). The distance focus–film was 375 cm and object–film was 20 cm (Figure 2.7). The distance focus–object was 375–20=355 cm.

Figure 2.23 In the cephalostat used in Groningen the right side of the child is turned toward the cassette for the lateral cephalogram. The earrods fix the head; the pointer P is placed on the left (skin) Orbitale. The face is turned toward the cassette for the frontal cephalogram.



Magnification of structures in the **median** plane.
A':A=375:(375–20)=1.056 Magnification: 1.056

Magnification of structures in the para-median plane 5 cm **left** of the median.
X':X=375:(375–(20+5))=1.071 Magnification: 1.071

5 cm **right** of the median:
Y':Y=375:(375–(20–5))=1.041 Magnification: 1.041

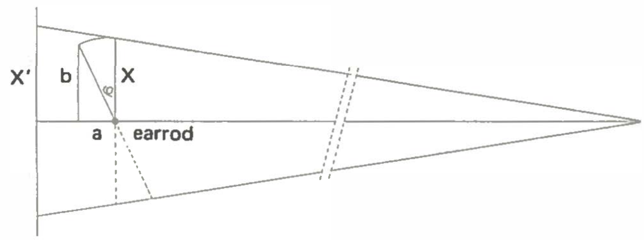
Since the intention in this investigation was to convert all the measured distances to their true values, in making computations it was assumed that:

a. The magnification of all structures in the median plane, caused by projection from a focal source, was 1.056.
b. Articulare (12 and 13) lay on, or very close to the central beam, and could therefore be assigned to both the median and paramedian planes.
c. The lines 12–18 and 13–17 lay in paramedian planes 5 cm left or right of the median; the magnification was respectively 1.071 and 1.041.
d. The estimated magnification for the lines 18–6' and 17–6' were 1.066 and 1.046 for left and right respectively.

The FORTRAN program that carried out these corrections is schematized in the flow chart in Figure 2.24.

Another systematic error occurs when a child's head is lopsided in the cephalostat because he (his ears) is not symmetrical. The distortion which this produces cannot be calculated, but it is presumably insignificant. The rotations of the head which can result were not found troublesome while analyzing the cephalograms. The source of random error originates in the inexact placement of the child in the cephalostat. A rotation of the head on the vertical axis is made virtually impossible by the earrods. On the other hand, a rotation on an axis through the earrods (nodding) is possible, and can amount to 10%. This error only occurs in the frontal cephalogram and can be estimated as follows (Figure 2.25).

Figure 2.25 Angle φ results from nodding on an axis through the earrods. By having the child sit in the cephalostat with a straight back, this error can be kept small.



$a = X \sin\varphi$
$b = X \cos\varphi$

If the rotation amounts to 10%, then $a = 0.174\,X$ and $b = 0.985\,X$

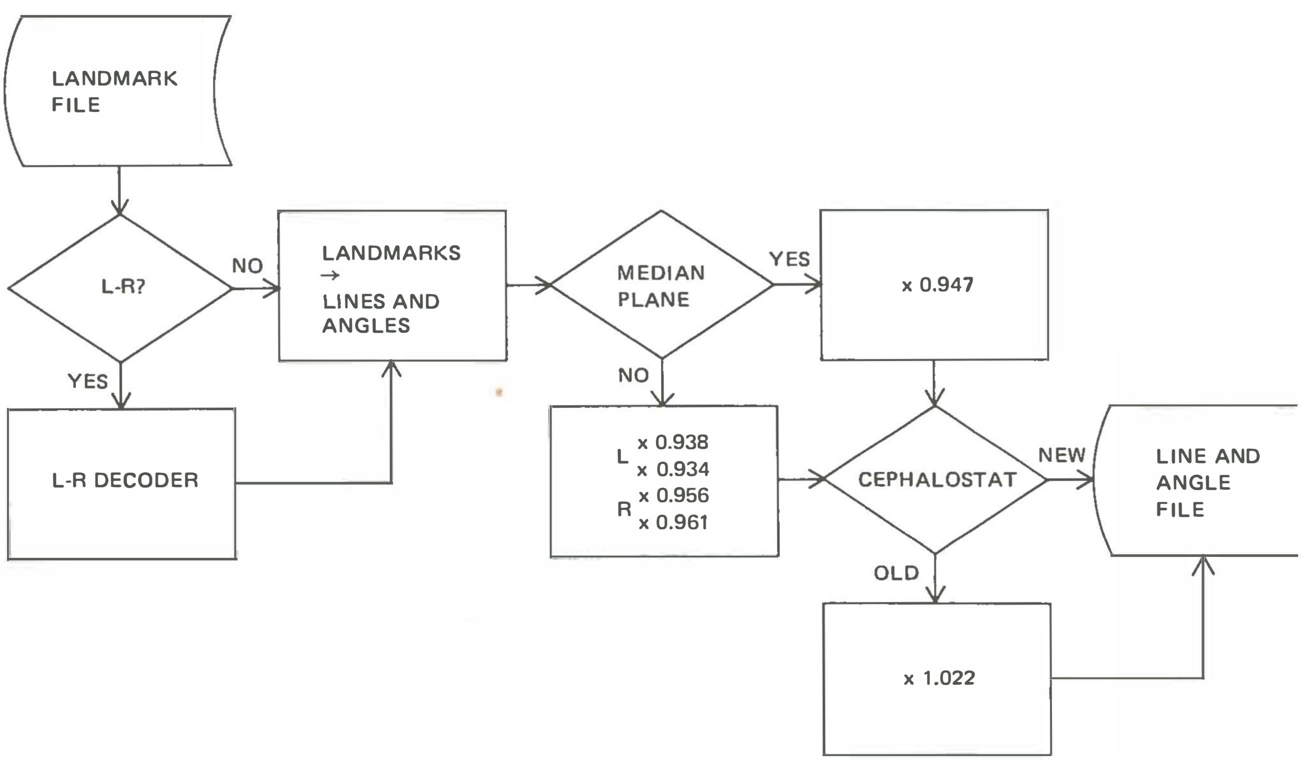
$X' : b = 375 : (375 - (20 - a))$ Magnification: 1.035

The magnification of structures in the median plane was 1.056. Rotation towards the film thus produces a relative diminution.

Rotation away from the film:

$X' : b = 375 : (375 - (20 + a))$ Magnification: 1.046

Figure 2.24 Flow chart Left–Right decoder.



In further calculations the error of the frontal projection was considered to have a mean 0; there was a magnification of 1.056.

Errors of measurements on the cephalogram

Systematic errors in measuring the cephalogram were kept for the most part within acceptable limits because accurate technical procedures were followed. The photographic material used maintained its size precisely; developing was standardized and took place automatically (difference in size before and after developing was 0.2%). The electronic equipment used for these measurements was gauged at 0.05 mm and 0.05 degrees according to the manufacturer.

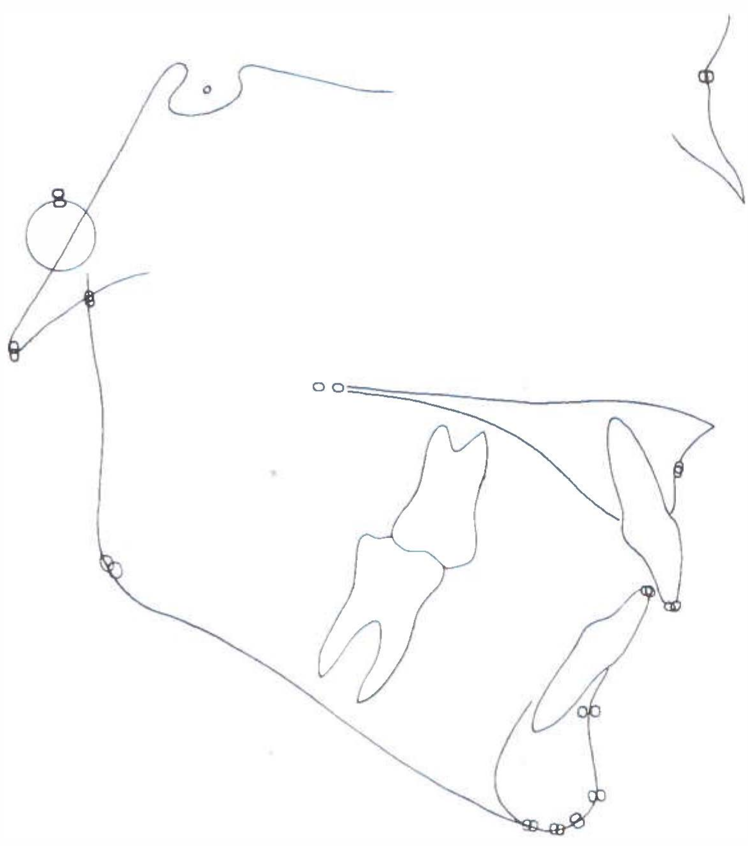
The random error during measurement is influenced by:

a. The determination of a landmark on the photos.
b. The choice of the landmarks used to determine a line.
c. The reading and recording of lines and angles.

(a) The precision with which landmarks can be determined is dependant upon:
- the quality of the cephalogram
- the contours on which the landmarks are located
- whether or not other structures are projected over the landmarks
- the presence of consecutive cephalograms

For example, quality is clearly important for point A on the lateral cephalogram, the contour is important at UIE, and overprojection often masks Basion. For some points, like Nasion and Basion, the availability of several cephalograms for the same child is an absolute necessity. The correct determination of a position on a single cephalogram is often impossible, and errors are almost certain to be made.
(b) The scattergram which results from a landmark's being determined many times on one and the same cephalogram is usually elliptical rather than circular, and follows the direction of the contour on which the landmark lies (Baumrind and Frantz 1971). This means that in choosing landmarks to be used for linear measurements, it should be realized that the aforementioned lines will demonstrate the least

Figure 2.26 Total of errors made. Each circle represents five measurements. Two circles lying beside each other occur when measurements are made on two photographs at an one-week interval.



dispersion lengthwise, when this "error ellipse" is perpendicular to the measurement direction. When determining angles, on the other hand, it is better if the error ellipse falls exactly in the extension of the side of the angle.
(c) The source of these errors is unambiguous. In this investigation the use of electronic equipment reduced this type of errors to a minimum. These operations were performed completely automatically.
In order to get an idea of the possible total of errors made, a child not included in the investigation was X-rayed twice with an interval of one week. The two lateral cephalograms were measured five times each along with the other films at random times during digitizing. The result is illustrated in Figure 2.26.

2.5.3 Orthopantomogram

The scoring of the calcification stage of the teeth of one half of the mandible according to the scale of Nolla was carried out twice. The average of the two scores was recorded. The difference between the highest and lowest score was minimal, and never amounted to more than 1 point.

2.5.4 Parma radiographs of right and left joints

To test the reproducibility of the ADJ qualification, ten radiographs were selected of children who had had no demonstrated deformations during the entire time-span of the investigation. Additionally, ten radiographs were selected of children who had no deformity during the entire time-span of the investigation. These twenty radiographs were anonymously evaluated. This test proved that it was possible to achieve complete reproducibility.

2.5.5 Photographs

Control of these photos revealed an incidental enlargement error of maximally 10%. The discussion of random errors in measuring X-rays applies to the photographs. These factors were not further taken into account in the study.

Chapter 3

Description of the variables

3.1 Introduction

Chapter 2 has described how the data collected were adapted for use in further statistical manipulations. The results of this process were transferred to a computer disk and stored on permanent file under the name ARTHROFILE. They were then permanently available for carrying out various operations.
This chapter describes what further preliminary steps were taken before analysis of the data could begin.
To begin with, the concepts employed were defined as precisely as possible. This is necessary to ensure that accurate and reliable categories are made in the operational phase of the study. A general distinction is made in this respect between the measurement data and the data obtained from the case history and clinical examination. Data obtained from measurements on cephalograms, photographs, and from the child itself (length of auricles and maximum mouth opening) are called **growth variables Y**. The data from the case histories and the remaining data, which were obtained during the yearly checkups, and which form possible relationships with the growth variables Y, are called explanatory or **X-factors**.

3.2 The X-factors

Since temporomandibuar joint dysfunction is the central issue in the investigation, a distinction is made in the definitions between the X-factor "dysfunction" and the other X-factors. Whether dysfunction was on the right or left side was not taken into account in the initial operational phase. See Chapter 6 on this topic.

3.2.1 Temporomandibular joint dysfunction

The concept temporomandibular joint dysfunction has only a purely descriptive meaning in this study. The terms "X-factor temporomandibular joint dysfunction" and "temporomandibular joint dysfunction" will therefore be used when the component characteristics are being referred to. These terms are meant to include those symptoms which are described only in general terms in the orthodontic literature, but which will be defined within narrow boundaries in this investigation. It is therefore extremely important at this point that an insight be provided into how the X-factor temporomandibular joint dysfunction is constructed. This X-factor is composed of **subjective symptoms** indicated by the child upon questioning at the first checkup; of **objective symptoms**, obtained by palpating the joints during the first checkup; and of deformities ascertained from the **Parma radiograph** during the total time-span of the investigation. One child can concurrently have several symptoms.
Figure 3.1 is compiled on the basis of the definitions and contingency tables which follow in this chapter.

Subjective symptoms

Much has been published about the broad scale of complaints commonly ascribed to temporomandibular joint dysfunction. The literature referred to in Chapter 1 only touches the surface of what has been written on this topic. The following aspects have therefore been selected in this study to form a definition for what will be classified as subjective symptoms.

Definition

In this study, under "sub_i" is understood the oral information revealed by the child himself –following a structured interrogation– about clicking, snapping or crepitation, about pain and about locking of one or both of the temporomandibular joints, or limitation in their movements. i=0, 1, 2 or 3 and indicates during which yearly checkup the symptoms were noted. If all these symptoms were absent for both joints in year i, the complex "sub_i" has a value of 0; in all other cases it has a value of 1.

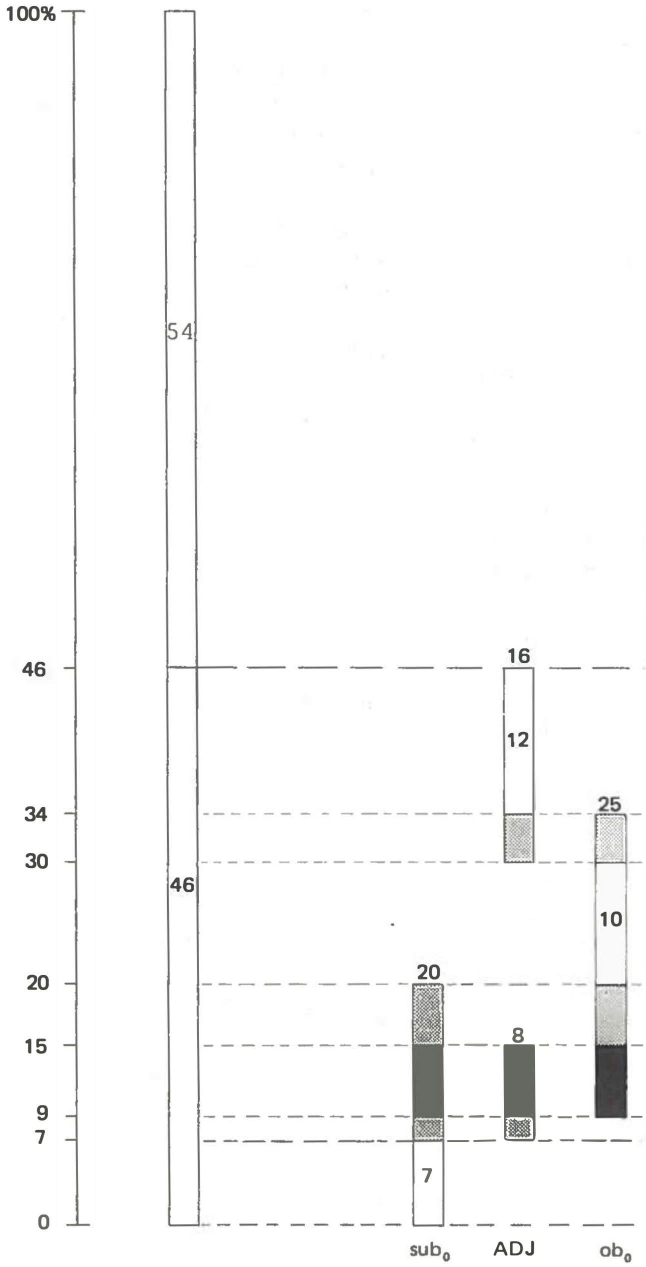
Objective symptoms

Clicking, snapping or crepitation of the joints was observed with a number of children during the yearly clinical examination. The temporomandibular joints were palpated every year, and the findings noted, to investigate possible relationships between these observations and growth variables Y.

Definition

In this investigation "ob_i" will be taken to mean the observation of clicking, snapping or crepitation while palpating the joints. i=0, 1, 2 or 3 and indicates at which yearly checkup the symptoms were noted. If all these symptoms were absent at year i, then the complex "ob_i" has a value of 0, and in all other cases a value of 1.

Figure 3.1 Constructing the X–factor temporomandibular joint dysfunction from the component parts.



The percentage of the total number of children that displays each of the three component parts of the X–factor temporomandibular joint dysfunction is vertically plotted for each component. The percentages are also given in numbers.
Forty–six percent of the children had temporomandibular joint dysfunction. From these, 45% had subjective symptoms at year 0, 55% had objective symptoms at year 0, and ADJ was diagnosed for 49%. Thus (45+55+49)%–100%=49% of the symptoms were reported more than once.

The dysfunction was composed of
16% purely subjective symptoms,
4% subjective symptoms and ADJ,
14% subjective and objective symptoms and ADJ,
11% subjective and objective symptoms,
22% purely objective symptoms,
8% objective symptoms and ADJ,
25% ADJ.

Arthrosis Deformans Juvenilis (juvenile deforming osteoarthritis)

Boering (1966) describes a considerable number (26%) of the temporomandibular joint patients whom he examined as being younger than twenty years old at their first visit. A simular X–ray projection of a deformity of the hip joint (Legg, Calvé, Perthes) led him to introduce the term **Arthrosis Deformans Juvenilis** (juvenile deforming osteoarthritis). Although Arthrosis Deformans is something of a misnomer –there is no evidence of loss of cartilage on X–rays– the terminology has been retained. There was, after all, very little literature on the subject, and to avoid further confusions no alternative is presented.
As described in section 2.2, the condyles of some of the children were deformed. The deformation observed on the radiograph was only diagnosed as Arthrosis Deformans Juvenilis, ADJ, when there was absolute certainty. A proper diagnosis requires considerable experience, but is seldom in doubt once it is made.

Definition

In this investigation, "$Rö_i$" is taken to mean the deformities of the condyle observed on the Parma radiograph, sometimes accompanied by radiolucent cysts under the cortex, a defect in the contour or marginal hypertrophy of the tubercle or condyle. i=0, 1, 2 or 3 and indicates during which yearly checkup the symptoms were noted. If all these symptoms were absent during year i for both condyles, then the complex "$Rö_i$" has a value 0, and in all other cases a value of 1.

Definition

In this investigation ADJ (juvenile deforming osteoarthritis) is taken to mean the observed deformities of the condyle, sometimes accompanied by radiolucent cysts under the cortex, a defect in the contour or marginal hypertrophy of the tubercle or condyle; the observations are obtained from Parma radiographs from year 0 to and including year 3. When the diagnosis ADJ is made, the complex "ADJ" has the value 1; otherwise the value is 0.

Combination of symptoms comprising the X-factor temporomandibular joint dysfunction

It is not known whether or not orthodontic treatment has an effect on the appearance of subjective or objective symptoms or ADJ. The phenomena which occurred in the children involved in the study during the treatment, and which were discovered during opening and closing of the mouth, cannot automatically be ascribed to temporomandibular joint dysfunction. It is after all highly possible that the use of activators or class II elastics evokes certain manifestations which closely resemble the symptoms described above; this makes it difficult, and sometimes almost impossible, to distinguish temporomandibular joint dysfunctions from "treatment complaints". Thus, the difference between pain resulting from dysfunction and fatigue caused by orthodontic treatment could be only a difference in degree. The jerking of a joint as the result of an uncoordinated movement which a child makes because the treatment has accustomed him to bite in a more forward position can easily be classified as snapping. On the other hand, the diagnosis of ADJ made from the Parma radiograph is much more reliable, and mistakes are unlikely.

The definition of the X-factor temporomandibular joint dysfunction as used in this study is composed of sub$_I$, ob$_I$ and ADJ. Only for the symptoms from year 0 for sub$_I$ and ob$_I$ does certainty exist that no influence was exerted -that is, that the symptoms cannot be ascribed to the orthodontic treatment. Therefore only sub$_0$ and ob$_0$ can be included in the definition; sub$_0$ A ob$_0$ and sub$_0$ V ob$_0$ remain as possible combinations. The relationship between the two combinations is diagramed in Table 3.1.

Table 3.1 Contingency tables of both combinations of subjective and objective symptoms.

sub$_0$ V ob$_0$	absent				present			
sub$_0$ A ob$_0$		↓	→	⇌		↓	←	⇌
absent	73	(100,	73,	65)	27	(69,	27,	24)
present	0	(0,	0,	0)	12	(31,	100,	11)

Elucidation.
Twenty-seven children (24%) were not identically classified; both component symptoms were reported for twelve chindren (11%) and no symptoms were registered for seventy-three children (65%). Additionally, 11% proved to conform to the combination sub$_0$ A ob$_0$ and 35% (24+11) to sub$_0$ V ob$_0$.

In section 2.2 has been shown that the changes in the temporomandibular joint visible on the radiograph are the result of a process that has been in motion for some time. Therefore, when a radiograph reveals a deformity at any particular stage in the documentation period, it can be assumed that the deformity already existed before that time. ADJ can therefore play a decisive role in the X-factor temporomandibular joint dysfunction; that is. if a deformity is detected on the Parma for one of the years 0 to and including 3, then temporomandibular joint dysfunction can be diagnosed. This can be illustrated as follows: of the twenty-five children for whom ADJ was diagnosed, eighteen were known in year 0, twenty-three in year 1 and the total twenty-five were known by year 2.

The relationship between sub$_0$ A ob$_0$, sub$_0$ V ob$_0$ and ADJ is presented in the Tables 3.2 to and including 3.7.

Table 3.2 Contingency table of sub$_0$ A ob$_0$ and ADJ.

ADJ	absent				present			
sub$_0$ A ob$_0$		↓	→	⇌		↓	←	⇌
absent	82	(94,	82,	73)	18	(72,	18,,	16)
present	5	(6,	42,	4)	7	(28,	58,	6)

Table 3.3 Contingency table of sub$_0$ V ob$_0$ and ADJ.

ADJ	absent				present			
sub$_0$ V ob$_0$		↓	→	⇌		↓	←	⇌
absent	61	(70,	84,	54)	12	(48,	16,	11)
present	26	(30,	67,	23)	13	(52,	33,	12)

Elucidation.
According to table 3.2, eighty-two children (73%) had none of the described symptoms while table 3.3 reported sixty-one children (54%) with no symptoms. In table 3.2, seven children (6%) displayed both sets of symptoms, in table 3.3 it was thirteen children (12%).

Table 3.4 Contingency table of temporomandibular joint dysfunction and subjective symptoms at year 0.

sub$_0$	absent				present			
dysfunction		↓	→	⇌		↓	←	⇌
absent	61	(69,	100,	54)	0	(0,	0,	0)
present	28	(31,	55,	25)	23	(100,	45,	21)

Table 3.5 Contingency table of temporomandibular joint dysfunction and objective symptoms at year 0.

ob_0	absent				present			
dysfunction		↓	→	⇌		↓	←	⇌
absent	61	(73,	100,	54)	0	(0,	0,	0)
present	23	(27,	45,	21)	28	(100,	55,	25)

Table 3.6 Contingency table of temporomandibular joint dysfunction and subjective or objective symptoms at year 0.

sub_0 V ob_0	absent				present			
dysfunction		↓	→	⇌		↓	←	⇌
absent	61	(84,	100,	54)	0	(0,	0,	0)
present	12	(16,	24,	11)	39	(100,	76,	35)

Table 3.7 Contingency table of temporomandibular joint dysfunction and ADJ.

ADJ	absent				present			
dysfunction		↓	→	⇌		↓	←	⇌
absent	61	(70,	100,	54)	0	(0,	0,	0)
present	26	(30,	51,	23)	25	(100,	49,	23)

Elucidation.
In the group of children with an Angle class II, division 1 malocclusion twenty-three (21%) had subjective symptoms, twenty-eight (25%) objective symptoms, thirty-nine (35%) subjective and/or objective symptoms, and twenty-five (23%) ADJ. In the group of children with temporomandibular joint dysfunction, 45% had subjective symptoms, 55% had objective symptoms, 76% had subjective and/or objective symptoms, and 49% had ADJ.

Two factors play a role in choosing between sub_0 A ob_0 and sub_0 V ob_0.

1. The underlying models for temporomandibular joint dysfunction.
   There are two possible models:
   a. sub_0 and ob_0 are expressions of different dysfunctions which may possibly occur in combination, or they are the expression of the same dysfunction at different stages in its development.
   b. sub_0 and ob_0 are expressions of the same dysfunction. Their occurence in combination is possibly an indication of the seriousness of dysfunction.
2. Erroneously calling "normal" children "deviant" or calling "deviant" children "normal".

In the investigation it is assumed that the observation of child and dentist is correct. With sub_0 V ob_0, children who are dubious according to model (b) are called "deviant". The "normal" group is pure.
With sub_0 A ob_0, children who are dubious according to model (b) are called "normal". The "deviant" group is pure. According to model (a), with sub_0 A ob_0, children who fulfill one of the criteria are called "normal", although they are not. In this case sub_0 V ob_0 gives a correct classification. It is not yet known whether model (a) or model (b) is correct. Generally, the literature pleads for (b). However, considering the moderate overlap of children with sub_0 and children with ob_0 (Figure 3.1), model (a) cannot be eliminated at this stage of the investigation. The criterion sub_0 V ob_0 is therefore used here, and the application of both components of this criterion will be analysed separately in a later phase of the study. A "normal" group that is as pure as possible is also necessary for such analysis, which is also a plea for the criterion sub_0 V ob_0.
With due regard to the considerations named above, the following definition of temporomandibular joint dysfunction has been constructed for this study.

Definition

Those children met the criteria for temporomandibular joint dysfunction in this study who at year 0 had subjectively or objectively determined symptoms such as clicking, snapping, crepitation or pain in one or both joints, as well as those for whom the Parma was deviant in any one year.
The relationship between the definition and its component parts is displayed in Tables 3.4 to and including Table 3.7.

3.2.2 The other X-factors

Age

The age of the children at the beginning of treatment has been converted into half years. Data from *An Atlas of Craniofacial Growth*, Riolo *et al.* (1974) was used as a model for predicting the direction of a possible effect of age and sex on the growth variables Y. Most of the growth variables Y have smaller values for girls than for boys, and most of the linear measurements increase with age.

Appliance

The children in this study, as previously stated, were treated with activator or with Begg appliance. A

divergent influence of these two types of treatment on growth is conceivable and must therefore be added as another possible explanatory factor; year 0, however is excepted because per definition none of the children had as yet been treated.
The children were chosen from a group that had been referred to the Department of Orthodontics by their dentist (first selection), that had been selected for treatment (second selection), and for which a certain type of treatment had been suggested (third selection). About the first selection can be asked why the dentist referred some of the children at an early, and others only at a later age. Perhaps a skeletal dysharmony was more decisive in the first group, and a dental problem in the second. Selections two and three were connected because the same person who decided for or against orthodontic treatment also chose the type of orthodontic appliance. One could say that this selection depended on "clinical judgement".
Thus two main groups of children were formed (unconsciously) by the division into types of treatment at year 0, although it was perhaps impossible at that time to give a precise enumeration of the differences between the groups.
As a result of these considerations, the X-factor appliance has as its actual meaning: **the respective type of appliance suggested.**

Active treatment time

The active treatment time, expressed in months, can, as an X-factor, never exceed the period during which the growth variables Y are being studied; it is therefore limited to zero months at year 0, twelve months at year 1, twenty-four months at year 2, and thirty-six months at year 3.
The active treatment time is understood to be the length of time necessary for active orthodontic treatment, and is therefore exclusive of possible preliminary treatment and/or a period with a retainer.

Trauma

It is conceivable that a hard blow on the jaw, eventually leaving behind a scar, has influenced the growth pattern due to injury to the temporomandibular joint. Observations of trauma and scar during the yearly checkups are combined into one X-factor, denoted as "trauma". Because it is assumed that there is not enough time (less than twelve months) for violence which occurs in the last year to exert a clear influence on the growth variables Y, a trauma in the last year is therefore not classified as "trauma".

Definition

In this investigation, trauma will be understood to be the observations of trauma or of a scar from the case history or the yearly checkup, in which the complex "trauma" has a value of 1 if a trauma or scar was reported up to and including year two; in all other cases the value is 0.

Oral habits

Possible influences from abnormal oral habits described in dental literature such as thumb-sucking and finger-sucking, nail-biting and gnashing of teeth can be treated in the same way as the factor violence. The total of these variables is combined into one X-factor.

Definition

In this investigation, oral habits will be understood to mean the observation of thumb-sucking or finger-sucking, nail-biting, gnashing or clenching of teeth in the case history or in all the yearly checkups, in which the complex "oral habits" receives a value of 0 if all the answers were negative; in all other cases the value is 1.

Forced bite

A forced bite occurs when the lower jaw does not close directly in occlusion when the teeth are brought together, but slides off as a result of premature contact or unfavorable relationships. However, a frequency table showed that only two forced bites had been observed during the first checkup; the number of cases increased to only four by the fourth examination. **Therefore this X-factor was discarded.**

Attrition

Attrition can indicate an excessive taxing of the oral tissues. It is conceivable that growth is affected because the movements have a strong forceful character. Especially during sleep, strong muscle movements of the masticatory system can be involved. This attrition is also included in the X-factors, even though an X-factor already exists of which gnashing of teeth is a component. Attrition is here considered to be an indication of gnashing of teeth of which the child himself is often unconscious. The relation between attrition and gnashing of teeth is presented in Table 3.8.

Table 3.8 Contingency table of attrition and gnashing of teeth at year 0.

gnashing \ attrition	absent	↓	→	⇄	present	↓	←	⇄
absent	84	(94,	82,	75)	19	(83,	18,	17)
present	5	(6,	56,	4)	4	(17,	44,	4)

Elucidation.
Eighty-four children (75%) did not gnash their teeth and had no attrition. Four children (4%) had attrition and gnashed their teeth. The observations were not in agreement for 21% (4+17).

Table X-factors

Except for X_1 to and including X_4, the X-factors were recoded to 0 -characteristic absent- and 1 -characteristic present. X_1 was converted to **age** at the beginning of the treatment, expressed in **half years**.

The coding for X_2 to and including X_4 can be seen in the Table. X_5 to and including X_8 have been defined in this chapter.

Table 3.9 X-factors.
The nomenclature, coding and division parameters of the X-factors as defined in section 3.2.

X_i + name	coding	division parameters
X_1 Age	0–35	mean 25.2; st.dev. 3.8
X_2 Sex	♂–♀	49 (44%) – 63 (56%)
X_3 Appliance	Act.-Begg	51 (46%) – 61 (54%)
X_4 Active treatment time	0–36	mean 19.8; st.dev. 7.7
X_5 trauma, scar		
Trauma	0–1	91 (81%) – 21 (18%)
X_6 sucking, nail-biting, gnashing		
Oral habits	0–1	46 (41%) – 66 (59%)
X Forced bite at year 0	0–1	110 (98%) – 2 (2%)
X_7 Attrition at year 0	0–1	89 (79%) – 23 (21%)
X_8 Dysfunction	0–1	61 (54%) – 51 (46%)

3.3 The growth variables Y

The computed angles and lines are defined in section 2.2 and comprise the vast majority of the growth variables Y. Three linear measurements which are carried out during the yearly checkups -the lengths of left and right auricles and maximum mouth-opening- have been added to them.
Boering (1976[1], 1976[2]) supposes that the length of the auricle could be a sensitive indicator of growth disturbances in the first branchial arch. An example is *dysostosis mandibulo facialis* in which the development of the auricle is clearly affected. The only eventual relationship which has been sought is that between the size of the auricle and the magnitude of other variables.
The maximum mouth-opening was measured to investigate whether or not the mouth-opening was different for children with temporomandibular joint dysfunction. So as to exclude any influence exerted by the orthodontic treatment or other factors on the measurement method employed, the overbite was added to the value obtained. In this investigation the overbite was calculated from data obtained from the cephalograms (section 2.4.3 and Figure 2.17).
The growth variables Y are summed up in Table 3.10, along with the means, the standard deviations and the number of observations.

Table 3.10 The exhaustive list of growth variables Y with their mean ($\bar{Y}_i$), standard deviation (s_i) and the number of cases for which it is computed (n_i) with i = 0 (year 0) and i = 3 (year 3). The angles and lines are defined in section 2.4.3.

Angular variables	$\bar{Y}_0$	s_0	n_0	$\bar{Y}_3$	s_3	n_3
∠ SN/FH	7.0°	3.7°	106	7.3°	3.4°	109
∠ SN/PP	7.6°	4.2°	110	8.2°	4.4°	111
∠ SN/OP	15.3°	4.6°	111	17.4°	4.2°	112
∠ SN/MP l	34.7°	5.7°	109	34.0°	6.0°	111
∠ SN/MP r	34.3°	5.9°	109	33.6°	6.0°	109
∠ SN/RP l	88.8°	5.0°	111	89.6°	5.3°	112
∠ SN/RP r	89.1°	4.8°	111	89.8°	5.2°	112
Gonial angle l	125.5°	6.6°	111	124.3°	7.0°	112
Gonial angle r	125.2°	6.7°	111	124.6°	6.5°	112
∠ RP/OP l	106.5°	5.3°	111	107.8°	4.9°	112
∠ RP/OP r	106.2°	5.2°	111	107.6°	5.2°	112
∠ S-N-Pg	76.1°	3.8°	111	77.1°	4.0°	112
∠ S-N-B	74.7°	3.8°	111	75.5°	3.9°	112
∠ S-N-A	80.4°	4.0°	98	79.9°	3.7°	81
∠ Ba-S-N	131.7°	5.0°	111	131.2°	5.0°	112
Y-axis l	89.0°	3.8°	109	89.1°	4.1°	109
Y-axis r	89.0°	3.8°	109	89.1°	4.1°	109
Linear variables						
TFH	108.4 mm	6.2 mm	111	115.3 mm	6.7 mm	112
UFH	48.0 mm	4.0 mm	111	50.8 mm	4.0 mm	112
LFH	58.9 mm	4.7 mm	111	63.3 mm	5.1 mm	112
PFH l	65.0 mm	5.1 mm	111	70.0 mm	5.5 mm	112
PFH r	64.5 mm	5.1 mm	111	69.5 mm	5.5 mm	112
S-N	66.1 mm	3.0 mm	110	68.2 mm	3.2 mm	110
S-Ar l	32.8 mm	4.1 mm	111	34.6 mm	3.4 mm	112
S-Ar r	32.9 mm	4.0 mm	111	34.6 mm	3.2 mm	112
Ar-N l	88.9 mm	4.7 mm	111	93.0 mm	4.7 mm	112
Ar-N r	88.9 mm	4.5 mm	111	93.1 mm	4.6 mm	112
S-Gn	110.4 mm	6.6 mm	111	118.0 mm	6.8 mm	112
Ar-Gn l	96.1 mm	6.6 mm	111	103.1 mm	6.7 mm	112
Ar-Gn r	96.1 mm	6.6 mm	111	103.1 mm	6.7 mm	112
Ar-Pg l	94.6 mm	6.5 mm	111	101.5 mm	6.5 mm	112
Ar-Pg r	94.6 mm	6.5 mm	111	101.6 mm	6.5 mm	112
Ba-Gn	97.6 mm	7.3 mm	110	104.7 mm	7.3 mm	109
Ba-Pg	96.6 mm	7.2 mm	110	103.6 mm	7.2 mm	109
Gol-Gol	2.1 mm	1.8 mm	111	2.3 mm	2.1 mm	112
Overjet	7.3 mm	2.9 mm	111	3.5 mm	1.7 mm	112
Overbite	3.5 mm	2.0 mm	111	2.6 mm	1.6 mm	112
Gol-Pg' l	68.2 mm	5.6 mm	111	72.7 mm	5.2 mm	112
Gol-Pg' r	66.9 mm	5.5 mm	111	71.6 mm	5.2 mm	112
Ar-Gol l	41.2 mm	4.3 mm	111	45.5 mm	4.8 mm	112
Ar-Gol r	40.7 mm	4.0 mm	111	44.0 mm	4.6 mm	112
Pr Ba-Pg/OP	85.8 mm	5.9 mm	110	92.3 mm	7.0 mm	109
Pr Ar-Pg/OP l	78.0 mm	5.4 mm	110	85.3 mm	6.5 mm	109
Pr Ar-Pg/OP r	78.0 mm	5.4 mm	110	85.4 mm	6.6 mm	109
Pr Ba-Gn/OP	84.1 mm	6.0 mm	110	91.2 mm	7.0 mm	109
Pr Ar-Gn/OP l	76.9 mm	5.6 mm	110	84.2 mm	6.6 mm	109
Pr Ar-Gn/OP r	76.9 mm	5.4 mm	110	84.3 mm	6.7 mm	109
Auricle l	59.9 mm	3.7 mm	112	61.7 mm	4.0 mm	112
Auricle r	60.1 mm	4.0 mm	112	62.0 mm	3.8 mm	112
Mouth + Overbite	53.0 mm	5.7 mm	112	53.7 mm	6.5 mm	112

Chapter 4

Description of the sample and the methods of statistical analysis

4.1 Introduction

This chapter describes various statistical operations. This involves first, defining the sample, and then choosing the level of significance at which the null hypothesis is to be rejected in statistical testing. Finally, the methods used in analyzing the data are briefly described.
The study was primarily concerned with the quality of the relationships between X-factors and growth variables Y (largely: case histories and measurement data). Some epidemiogical aspects will be discussed in Chapter 7 as an interesting additional result of the manipulations.

Originally, an attempt was made to divide the X-factors defined in Chapter 3 into groups. Using KOMPLOT (1975), a program for the Control Data Cyber 74-16 computer, composite graphs were made of the computed means from these groups on an online mechanical drum plotter. The data from year 0 to and including year 4 and the ages 8.5 to and including 16.5 from the study were used in this operation. This method provided some indications of relationships but gave no insight into their size and quality. An analytical, statistical approach was therefore chosen to allow for an investigation which was as complete and accurate as possible.
Upon commencement of the statistical manipulations, the documentation for all the children was not available for year 4. Because the consequences for the relationships investigated were uncertain, year 4 was not used for the statistical operations. The data from years 1 and 2 were used only incidentally.

4.2 Description of the sample

To make generalized conclusions based on statistical results, the group of children studied must be considered to be a random sample of a population of children having the same characteristics as those who qualified for treatment with activator or Begg. The way in which the children were selected is described in section 2.1. The ratio of boys to girls in the investigation was 7:9. The distribution of ages was about normal; the youngest child was 8.5 years, the oldest 16.5 (Figure 4.1).

Figure 4.1 Histogram of the age pattern in the sample.

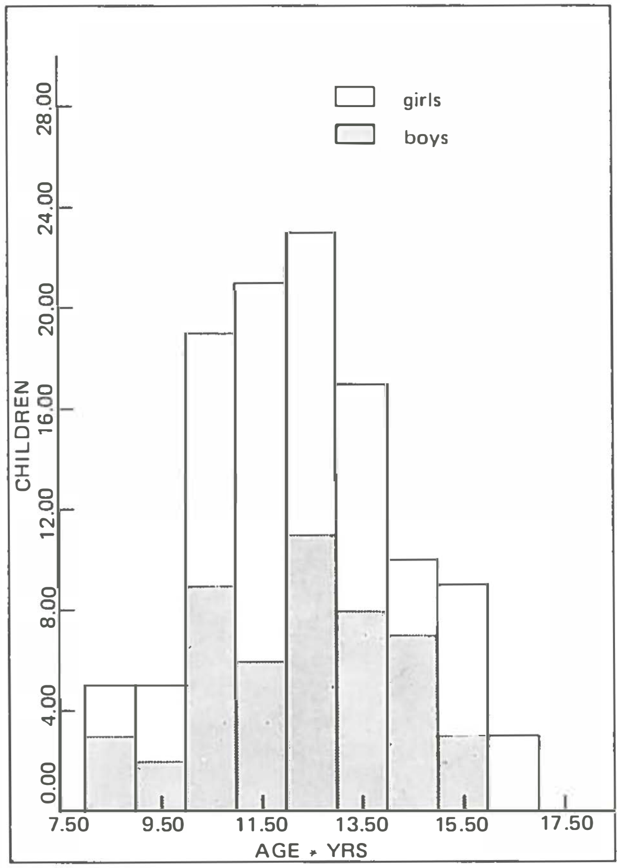


Table 4.1 Contingency table sex and appliance.

sex	appliance activator	↓	→	⇄	Begg II	↓	←	⇄
♂	24	(47,	49,	21)	25	(41,	51,	22)
♀	27	(53,	43,	24)	36	(59,	57,	32)

Elucidation.
Twenty-four boys were treated with activator; this was 47% of the total activator treatment (column), 49% of the total number of boys and 21% of the total number of children. For the Begg therapy this was respectively 25%, 41%, 51% and 22%.

Twenty-seven girls were treated with activator; this was 53% of all the activator treatment, 43% of all the girls and 24% of all the children. This was respectively 36%, 59%, 57% and 32% for Begg.

It is interesting to note that relatively slightly more girls than boys were treated with Begg.

Whenever general conclusions have to be drawn on the basis of the results of statistical manipulations, certain risks are inherent to this generalization. The extent of this risk can be computed by using a test statistic. If its sampling distribution is known, the computed statistic can be looked up in a table to determine the probability (p) that a certain outcome is found in a sample if the null hypothesis is true, that is, if it holds for the population. If this probability is less than a certain significance level which has been selected in advance, then the null hypothesis is rejected in favor of the alternative hypothesis. The test can be one-tailed or two-tailed depending on the specifications of the alternative hypothesis. If the direction under the alternative is known, which means there are certain reasons to state beforehand which sign holds for the relation when the null hypothesis is rejected, then an one-tailed test can be used. If its direction is undetermined, that is, if the relation between the variables could be either positive or negative, then a two-tailed test is used.

The significance level (α) for all the statistical tests in this study is 0.05. When $p<\alpha(=0.05)$, then the null hypothesis is rejected in favor of the alternative hypothesis.

Boering (1966, 1976[1], 1976[2]) presumed that pathological disturbance in a joint results in retardation of the growth at the condyle. This could cause the mandible on the side affected to develop less harmoniously with other parts of the craniofacial skeleton. If this (alternative) hypothesis is true, then the presence of temporomandibular joint dysfunction will produce smaller values for the growth variables Y. The direction of the effect is thus determined under the alternative hypothesis, which makes it possible to use an one-tailed test.

Extensive data are available in the literature about the effect of age and sex on skull growth (among others Björk 1947; Nanda 1955; Harris 1962; Maj and Luzi 1963, 1964; Enlow and Harris 1964; Tracy and Savara 1966; Björk and Helm 1967; Tofani 1972; Ingervall and Lennartsson 1972; Moyers 1973; Control.. 1975; Enlow 1975[1]). In recent publications especially, the quantitative aspect of these influences are emphasized (Riolo *et al.* 1974; Broadbent *et al.* 1975). **By using the tables of Riolo *et al.*, the direction of the effect in the present investigation can be predicted, so that an one-tailed test can be used in this case.**

Opinion is divided about the effects of the various methods of orthodontic treatment (Symposium...1973; De Laat 1974; Levin 1975). **The effects of influences such as trauma, oral habits, forced bite and gnashing of teeth, though apparently obvious, are likewise impossible to predict with accuracy. The direction of the effect is therefore indeterminate, and a two-tailed test must be used.**

Section 4.3

Description of the methods of statistical analysis

Regression analysis

Growth can be considered to be determined by influences such as time, sex, predisposition and external factors. Orthodontic treatment is classified as one of these external factors. Growth is determined quantitatively by measuring priorly specified variables that change over time. A mathematical model can be used to explain growth as a dependent variable (Y) with a combination of growth-influencing factors ($X_1 ... X_p$). The success of the explanation depends on the number of influential factors that are known -in relation to the actual (unknown) number- and the correct choice of the model. Since Tanner (1962), for example, has summed up as many as fifteen factors influencing growth (socio-economic influences, for example), many of which we have failed to measure, our explanation cannot be expected to approach 100%. However, if temporomandibular joint dysfunction is definitively demonstrated as an explanatory factor, then the total number of unknown factors has at least been diminished by one. By eliminating this factor, the probability is increased that influence of factors such as trauma or oral habits on growth variables Y can be proved.
Using the investigated sample, estimates are made for $\beta_0, \beta_1, ... \beta_i ... \beta_p$ in the multiple linear regression model $Y=\beta_0+\beta_1 X_1+...\beta_i X_i+...\beta_p X_p$.
In a multidimensional space, the influence of each X-factor on one growth variable Y is mathematically considered, while the influence of the other X-factors is eliminated as completely as possible. In order to test the relation of the X-factor with the growth variable Y in this model, a test statistic is computed. The chosen significance level, together with the degrees of freedom, determines the critical value of the test statistic. When a number of assumptions are made, the null hypothesis in this case is $\beta_i=0 (i=1,...p)$, that is, in this regression model the relevant X-factor is not related to the growth variable Y. If $p<0.05$, then the explanation of Y by X is called significant at $\alpha<0.05$. Finally, the computed multiple correlation coefficient

describes the proportion of variance of growth variable Y explained by the linear combination of X-factors, that is the goodness of fit of the regression equation.

Analysis of variance

An analysis of variance is one way to test a pronouncement of whether or not different samples can have been drawn from identical populations. If the samples differ in one respect, then this factor can easily be eliminated by creating groups based on this factor. The children were assigned to a group according to definitions to be given later. These four groups were: one with children with only a dominant left dysfunction, one with children with only a dominant right dysfunction, one with children with a dysfunction on both sides, and one with children with no temporomandibular joint dysfunction. The groups are considered to be random samples from normally distributed populations with equal variance. A test statistic is then computed, this time with a F-distribution, to test the hypothesis that the populations from which the samples are drawn also have the same mean. Further, Bartlett's test is used to investigate whether or not violence has been done to the presumed equality of variance.
The difference between the groups is called significant when $p<0.05$.

The Chi-square (χ^2) test for contingency tables

This test is used to investigate whether or not two variables measured at a nominal scale are related to one another. A nominal scale means that there is no rank order in the categories of the variables.
The test determines whether or not it can be assumed that the categories of the one variable are equally distributed over the categories of the other variables in the population from which the sample has been drawn. The null hypothesis therefore states that these distributions are equal. This equal distribution is then estimated from the marginal totals by weighing the relative frequency of the sums of the columns with the number of observations in the row. The test statistic has a Chi-square distribution with a number of degrees of freedom equal to (the number of rows -1)$\times$(the number of columns -1).
The relation between both variables is called significant when $p<0.05$.

Student's t-test

Student's t-test can be used to determine whether or not the mean of a continuous variable in two groups is different. Assumptions for the test are that the variable being investigated has a normal distribution with the equal variance in the populations from which the samples are presumed to be randomly drawn. In framing the null hypothesis it is assumed that the samples come from identical populations. The alternative hypothesis is that the populations have a different mean. The computed test statistic by Student's t-test has a t-distribution.
The difference between the means is called significant when $p<0.05$.

Cohen's unweighted kappa (κ)

In certain cases the task is to determine whether or not two means of assessment, for example sub_0 and ADJ, measure the same phenomenon. For these cases a two by two table for example can be set up. When their agreement is perfect, all the observations will fall in the diagonal of this table. The more observations which fall outside the diagonal, the worse the agreement. Yet even if there were no relation at all between sub_0 and ADJ, some observations could fall by chance in the diagonal. The κ determines whether or not the sum of the diagonal cells is greater than what might be expected to occur by chance. A correction for these chance occurrences, estimated from the marginal totals, is also applied. The computed test statistic has a standard normal distribution.
The agreement of the two variables is called significant when $p<0.05$. The unweighted κ and its test statistic were computed with a program written in ALGOL 60.

Factor analysis

Factor analysis is used in this study to describe individuals characterized by a set of growth variables Y with a smaller number of more easily interpreted variables than the original set. This involves a negligible loss of substantial information. It is designed to identify certain structures in the growth variables Y. Three essential steps in the procedure can be distinguished:

a. A matrix of (product moment) correlation coefficients is computed from the data. Each coefficient measures the –linear– relationship between two variables.
b. Using this correlation matrix, a number of new variables called factors, are computed by combining the original variables. The set of factors is called a factor matrix; this consist of factor loadings which are measures of the strength of the relationship of the variable in question with the factor.
c. Finally, a number of factors is rotated according to the Varimax criterion. This implies that loadings which are already high are raised, and loadings which are already low all lowered. As a result of this operation it becomes more obvious which variables are closely related to a factor, and which variables have little or no relation to a factor; thus rotation yields factors which are conceptually clearer. These rotated factors can then be considered as structures in the set of growth variables Y.

Chapter 5

Regression analysis

5.1 Introduction

In this chapter a selection is made from the growth variables Y so that the number of regression analyses to be interpreted is diminished. A discussion then follows of how the results should be interpreted. The results of several regression analyses are then compared with data found in the literature with the intention of gauging the reliability of the model. Results, grouped according to explanatory factor, are discussed. As far as can be determined multiple regression analysis has never previously been used in this form to explain craniofacial growth. Except for Howell (1971) and Harris (1971), references to literature are consequently lacking.

The regression model used here is based on two assumptions (Smillie 1966):

a. The residuals, to take as the part which is not explained in the model, are mutually independent and normally distributed with a mean of 0 and equal variance.
b. The relationship between the dependent and independent variables is linear.

This linear relationship may be doubtful in the case of age because of the acceleration of growth which is known as the adolescent growth spurt. Complicating factors in this connection can be the difference in the children's chronological age at the start of the study, the difference in the outset of the adolescent growth spurt and the fact that the effect of the orthodontic therapy and of temporomandibular joint dysfunction on growth is insufficiently understood. It is therefore unclear precisely which mathematical function can be used to describe the relationship between age and growth variables Y. The most simple relationship, a linear one, is therefore assumed.
The results of the regression analysis can provide an explanation of the growth variables Y when used along with the various X-factors. Conversely, growth predictions can also be made. That is, if all the values of the X-factors are known, then a prediction can be made for the matching growth variable Y.

5.2 Reduction in the number of growth variables Y

The determination of the position and the displacement of the mandible with respect to the rest of the skull was the central factor affecting the choice of lines and angles to be measured as described in section 2.2. That is, lines and angles were constructed from a number of landmarks at various positions within the skull for the purpose of pinning down mandibular locations and relationships.
The first hypothesis to be investigated was that a relationship exists between the X-factors and the growth variables Y in a sagittal plane, which is the direction of the strongest growth. A mean was therefore computed and retained for use in those cases where a different measurement had been made for right and left sides. The X-factors were also coded without a distinction right/left for this purpose.
The influence of the factors in the transversal direction will be handled in Chapter 6; for that analysis right and left sides will be coded separately.
The total set of linear and angular measurements displays clusters of highly correlated measurements. This is due to the morphology of the skull on the one hand, and on the other hand, to the fact that a number of virtually equivalent variables have been measured in order to obtain a greater certainty of the relevance of these measurements. For example, both the distances Basion-Pogonion and Basion-Gnathion were measured, though the lines connecting these points are the expression of the same anatomical dimension. A factor analysis was therefore carried out to discover possible correlations among the growth variables Y. A principal component analysis was carried out first; a Varimax rotation followed. This resulted in a slight reduction in the number of growth variables Y which was designed to avoid nearly identical outcomes in the regression analysis. An interpretation of the skeletal structural relationships which this factor analysis demonstrated is beyond the scope of this chapter. The possibilities inherent in the use of factor analysis for gaining insights into the structure of a set of growth variables Y are more fully discussed in Chapter 9.
Table 5.1 gives a summation of the growth variables Y after they have been reduced, with a reference to the chapters where they were first described, the tables with their definitions, and the figures and table containing their means from year 0 and year 3.

5.3 Illustration of the regression model and description of the results

The regression analysis yielded an **estimated regression coefficient** per growth variable Y for each X-factor considered; this coefficient can be seen as a measure of the X-factor's influence on the growth variable Y. Further, the analysis delivered a **standard**

Table 5.1 The growth variables Y in the regression analysis. The growth variables Y after reduction obtained by using factor analysis. The mean has been computed when there were separate measurements for left and right.

	Definition			Mean
	Chapter	Tabel	Figure	Tabel
Auricle	2.2.2		2.5	3.10
Mouth	2.2.2			3.10
∠ SN/OP	2.4.3	2.1	2.13	3.10
∠ SN/MP	2.4.3	2.1	2.13	3.10
∠ SN/RP	2.4.3	2.1	2.13	3.10
Gonial angle	2.4.3	2.2	2.14	3.10
∠ RP/OP	2.4.3	2.2	2.14	3.10
∠ S-N-Pg	2.4.3	2.2	2.14	3.10
∠ S-N-A	2.4.3	2.2	2.14	3.10
∠ Ba-S-N	2.4.3	2.2	2.14	3.10
Y-axis	2.4.3	2.2	2.14	3.10
TFH Total Face Height	2.4.3	2.3	2.16	3.10
UFH Upper Face Height	2.4.3	2.3	2.16	3.10
LFH Lower Face Height	2.4.3	2.3	2.16	3.10
PFH Posterior Face Height	2.4.3	2.3	2.16	3.10
S-N	2.4.3	2.3	2.15	3.10
S-Ar	2.4.3	2.3	2.15	3.10
Ar-N	2.4.3	2.3	2.15	3.10
S-Gn	2.4.3	2.3	2.15	3.10
Ar-Gn	2.4.3	2.3	2.15	3.10
Ba-Gn	2.4.3	2.3	2.15	3.10
Gol-Gol	2.4.3	2.3		3.10
Overjet	2.4.3	2.4	2.17	3.10
Overbite	2.4.3	2.4	2.17	3.10
Gol-Pg'	2.4.3	2.4	2.16	3.10
Ar-Gol	2.4.3	2.4	2.16	3.10
Pr Ba-Pg/OP	2.4.3	2.4	2.16	3.10
Pr Ar-Pg/OP	2.4.3	2.4	2.16	3.10

deviation, which expresses the precision of the estimator, and a **test statistic.** The **multiple correlation coefficient and its square** are computed. The square of the multiple correlation coefficient can be considered as a measure of the explained variance. The value obtained for the regression coefficient corresponds to the change to be expected in Y when the X being considered changes with one unit. For example, the influence of age is the number of **half** years times the regression coefficient (age is expressed in **half** years). In this way, a statement can be made about the expected value of the growth variable Y by filling in the value of the X-factors. An example of the procedures followed can be seen in Table 5.2 which shows a portion of the computer output given by the module REGRESSION. It contains Y=distance Basion–Gnathion (mean 97.6 mm, standard deviation 7.3); X_1 to and including X_7 are the X-factors as defined in Table 3.9.

The multiple correlation coefficient differs significantly from 0; that is, X_1 to and including X_7 contribute to the explanation of the distance Basion–Gnathion as it was measured for 110 children. The percentage of the variance explained is forty-five. From a table can be seen that with 102 degrees of freedom the critical value for two-tailed testing lies at 1.99. Those X-factors for which the computed test statistic has a value of >1.99 with two-tailed testing are defined as significantly different from 0. With 102 degrees of freedom the one-sided critical value lies at 1.67. The statistic obtained for β_0, β_1, β_2 and β_7 with one-tailed testing is significant at the significance level set above; the critical values given above for two-tailed testing apply for β_0, β_1 and β_2.

The regression coefficient for the different X-factors is computed for the growth variables Y at year 0 and year 3. The outcomes for year 0 can be considered as being the results obtained from a random sample from a population of children who qualify for orthodontic treatment of a class II, division 1 malocclusion. An attempt was made to use the year 3 outcomes to gain an insight into the changes that occurred over time, and which were the combined result of growth and orthodontic treatment, along with other factors. A total of fifty-six regression analyses were carried out.

Testing of the model for the influence of the X-factors age and sex

The reliability of the model will be illustrated with four regression analyses. A computer output is constructed in Table 5.3 from which the regression coefficients for age (3), sex (13) and temporomandibular joint dysfunction (584, identical to 585 in Table 5.2) have been selected for discussion. The growth variables Y at year 0 and year 3 are Sella–Nasion (577,580) and Sella–Gnathion (165,426). These two variables have been chosen because the first grows very little and the second grows a great deal in a three-year time period.

The age (3) was coded in half years; the sex (13) was coded 1 for boys and 2 for girls; temporomandibular joint dysfunction (584) was coded 0 for dysfunction absent, and 1 dysfunction present. The one-tailed critical value lies at t=1.67.
No influence of temporomandibular joint dysfunction on the Sella–Nasion distance could be demonstrated at year 0 or at year 3. Influence on the Sella–Gnathion distance could be clearly demonstrated, and amounted to 2.2 mm at year 0 and 2.0 mm at year 3.
From Table 5.3 can be inferred that the mean distance Sella–Nasion for the total population increases at a rate of 0.4 mm per year (0.2 mm per half year) which was about to be expected. Sella–Gnathion, on the other hand, increases on the average 2.2 mm per year (1.1 mm per half year) at year 0, for young children, while the increase at year 3, for older children, is 1.4 mm per year (0.7 mm per half year). There is therefore a decrease in the rate at which

```
                                    ******************
                                    *** REGRESSION ***
                                    ******************

REGRESSION MODEL WITH DEPENDENT VARIABLE :         173
AND CONCOMITANT VARIABLE(S) :       3      13      14     586     587     111     585

NUMBER OF COMPLETE INDIVIDUALS FOR THIS REGRESSION MODEL =  110
```

VAR	MEAN	STDEV
3	25.17	3.87
13	1.57	0.50
14	1.55	0.50
586	0.19	0.39
587	0.59	0.49
111	1.28	0.67
585	0.45	0.50

	ESTIMATED REGRESSION COEFFICIENT	STANDARD DEVIATION	VALUE OF T(102) - STATISTIC
CONSTANT TERM :	73.2906	4.2305	17.3244
VARIABLE NR : 3	1.1047	0.1836	6.0154
13	-2.7821	1.1041	-2.5199
14	1.8509	1.4066	1.3159
586	0.7494	1.3863	0.5406
587	0.1394	1.1225	0.1242
111	-0.9910	0.8398	-1.1800
585	-2.2108	1.1212	-1.9717

```
ESTIMATED VARIANCE OF ERROR =                    31.6803

ESTIMATED STANDARD DEVIATION OF ERROR =           5.6285

VALUE OF F(  7,  102) - STATISTIC =              11.7064

MULTIPLE CORRELATION COEFFICIENT =                0.6674

SQUARED MULTIPLE CORRELATION COEFFICIENT =        0.4455
```

Table 5.3 Partial, combined, computer output of four regression analyses. See text.

REGRESSION MODEL WITH DEPENDENT VARIABLE : 165

		ESTIMATED REGRESSION COEFFICIENT	STANDARD DEVIATION	VALUE OF T(103) - STATISTIC
CONSTANT TERM :		88.4579	3.8127	23.2006
VARIABLE NR :	3	1.0723	0.1632	6.5709
	13	-3.3047	0.9944	-3.3233
	14	0.5995	1.2541	0.4780
	586	2.0310	1.2518	1.6224
	587	-1.2069	1.0236	-1.1791
	111	-0.6805	1.2774	-0.5327
	584	-2.1727	1.0095	-2.1524

REGRESSION MODEL WITH DEPENDENT VARIABLE : 426

		ESTIMATED REGRESSION COEFFICIENT	STANDARD DEVIATION	VALUE OF T(103) - STATISTIC
CONSTANT TERM :		111.9091	5.2643	21.2582
VARIABLE NR :	3	0.6824	0.1733	3.9383
	13	-6.0800	1.1002	-5.5260
	14	0.0042	1.3561	0.0031
	15	-0.0143	0.0703	-0.2028
	586	1.9635	1.3659	1.4375
	587	-1.4539	1.0878	-1.3366
	605	0.0587	2.9602	0.0198
	584	-1.9776	1.1043	-1.7907

REGRESSION MODEL WITH DEPENDENT VARIABLE : 577

		ESTIMATED REGRESSION COEFFICIENT	STANDARD DEVIATION	VALUE OF T(102) - STATISTIC
CONSTANT TERM :		62.8156	1.9256	32.6211
VARIABLE NR :	3	0.2388	0.0833	2.8669
	13	-2.3357	0.5111	-4.5703
	14	0.6149	0.6481	0.9487
	586	0.4381	0.6403	0.6842
	587	-0.6561	0.5211	-1.2590
	111	0.5038	0.6388	0.7886
	584	-0.2331	0.5168	-0.4510

REGRESSION MODEL WITH DEPENDENT VARIABLE : 580

		ESTIMATED REGRESSION COEFFICIENT	STANDARD DEVIATION	VALUE OF T(101) - STATISTIC
CONSTANT TERM :		69.2847	2.6506	26.1395
VARIABLE NR :	3	0.1838	0.0875	2.1010
	13	-3.2428	0.5560	-5.8319
	14	0.3810	0.6886	0.5534
	15	0.0102	0.0353	0.2894
	586	0.2325	0.6857	0.3391
	587	-0.8898	0.5504	-1.6166
	605	-0.8682	1.4849	-0.5847
	584	-0.2122	0.5590	-0.3796

Sella-Gnathion increases in length. The following information is presented for boys and girls separately. The distance Sella-Nasion for girls is on the average 2.3 mm shorter at year 0 than for boys. At the end of three years this difference has increased to 3.2 mm. The increase in this boy-girl difference is even more pronounced for the Sella-Gnathion distance -from 3.3 mm at year 0 to 6.1 mm at year 3.

The results for both age and sex cannot be directly compared with data from *An Atlas of Craniofacial Growth*, Riolo *et al.* (1974). In the first place, Riolo *et al.* did not mention with what factor their cephalograms were enlarged; in the second place, the boy-girl ratio and the age distribution can affect the cross-sectional averages.
A factor (0.896) was derived from data acquired through supplemental inquiry so that the values given in Riolo *et al.* could be transformed into natural size dimensions. The uneven distribution of the two sexes and the cross-sectional elements were adjusted as well as possible so that a comparison could be made. For year 0, 5 times the measurement from Riolo *et al.* for twelve-year old boys was added to 6 times the same measurement for twelve-year old girls. This value is divided by 11 and then multiplied by 0.9. This yielded a measurement comparable to the one used in this study. The same relationship is assumed for year 3, but with a mean age of fifteen years. Interpolation between twelve and thirteen, and between fifteen and sixteen years was abandoned.
Table 5.4 gives an impression of the findings from Sella-Nasion and Sella-Gnathion at year 0 and year 3.

Table 5.4 Findings for S-N and S-Gn from this study compared to Riolo *et al. (1974).*

	mean increase per half year	mean difference girls/boys		
Riolo *et al.*	0.4	3.0	$S\text{-}N_0$	577
This study	0.2	2.3		
Riolo *et al.*	0.4	3.0	$S\text{-}N_3$	580
This study	0.2	3.2		
Riolo *et al.*	1.1	4.3	$S\text{-}Gn_0$	165
This study	1.1	3.3		
Riolo *et al.*	1.2	8.1	$S\text{-}Gn_3$	426
This study	0.7	6.1		

The data from Riolo *et al.* (1974) were adapted to make comparison possible (see text). The -fixed- cephalostat data were provided by F.P.G.M. Van der Linden, D.D.S., Ph.D.

Additionally, it should be remembered that the data from Riolo *et al.* were derived from children with normal occlusion, while in this study only children with an Angle class II, division 1 malocclusion were involved.

Table 5.4 shows agreement in magnitude and direction between data from Riolo *et al.* and the outcomes of the regression analysis. Each following regression analysis was controlled with respect to the outcomes for age and sex to see whether or not they agreed with Riolo *et al.* No contradictions were ever ascertained.

The influence of the X-factor appliance

The following significant regression coefficients for this X-factor are noted in Table 5.5.

Table 5.5 The results for the factor appliance.

	year 0	year 3
∠ SN/OP	−3.0	−0.9 NS
∠ SN/MP	−3.4	−2.0
UFH	+1.5	+0.7 NS
S-Ar	+1.9	+0.9 NS
Gol-Pg′	+2.0	+0.5 NS
Overjet	+1.3 NS	−1.7
Overbite	+0.4 NS	−1.0

The significant regression coefficients at year 0 and at year 3 for the factor appliance are given in Table 5.5. Appliance was coded 1 for activator, 2 for Begg. This means that the table can be read as the mean difference in growth variables Y for Begg compared to activator.

At the beginning of treatment, at year 0, the children who were to receive Begg therapy were already different in some respects from those for whom activator therapy was indicated. However, these differences could not be ascribed to age or sex, for instance.
The Occlusal Plane -OP- and the Mandibular Plane -MP- of the group with Begg appliance ran about three degrees more parallel to the Sella-Nasion plane than the same planes of the group with activator; the distance S-Ar and the upper face height, UFH, were respectively 1.9 and 1.5 mm greater. The mandibular corpus was 2 mm longer. After three years the group with Begg appliance displayed a 2° smaller ∠SN/MP, a 1.7 mm smaller overjet and 1.0 mm less overbite than the group with activator.

The influence of the X-factor treatment time

The influence of this X-factor is reproduced in Table 5.6. A separate analysis was made of the activator and the Begg appliance for the factor treatment time, so that the results could be more accurately interpreted.

Table 5.6 Results at year 3 for the group with activator and the group with Begg separately, for the X-factor active treatment time.

	activator	Begg
Mouth	+0.27	−0.19 NS
∠ SN/MP	−0.03 NS	−0.34
∠ Ba-S-N	+0.16	+0.01 NS
Overjet	+0.04 NS	−0.07

The significated regression coefficients, **per month of active treatment**, for activator and Begg.

The mean treatment time for both the group with Begg and the group with activator was twenty months.
In the group with activator the maximum mouth opening increased in twenty months with an average of 20×0.27=5.4 mm. In this same period, the ∠Ba-S-N became 3.2° larger on the average.
For the group with Begg appliance, ∠SN-MP became an average 6.8° smaller in a twenty-month period. The overjet diminished by a mean 1.4 mm.

The influence of the X-factor trauma

The influence of this factor is reproduced in Table 5.7; the factor is defined in Chapter 3.

In order to present the results graphically, polygons derived from the data were constructed.

Table 5.7 Results for the X-factor trauma.

	year 0	year 3
Gonial angle	+3.3	+3.4
TFH	+3.5	+3.4
UFH	+2.2	+1.6 NS
S-Ar	+2.4	+0.9 NS

Significant regression coefficient following a massive trauma of the chin. Trauma was coded 0 for never a trauma, and 1 for trauma. This means that the tables can be read as the mean difference in the growth variables Y for the children with trauma in the case history compared with children without trauma in the case history.

The tracing is drawn by hand through the means of all the original landmarks and angles from the children without temporomandibular joint dysfunction at year 0.
The reference polygon is made by connecting Sella, Nasion, Pogonion, the projection of the Pogonion on the Mandibular Plane, the Mandibular Plane, the Ramal Plane and the connection of Articulare with Sella. The polygons are superimposed along Sella-Nasion, registered at Sella.

The difference between the two polygons is the influence of the X-factor "trauma" as computed by the regression analyses. The reference polygon (thin line) from Figure 5.1 served as the basis from which the "trauma" polygon was constructed.
A clear and consistent influence of trauma could be detected in the untreated children. The result of this is illustrated in the polygon 5.2. The gonial angle of the children with a trauma in their case histories was on the average 3.3° larger and S-Ar was 2.4 mm greater than the gonial angle and S-Ar of the children without trauma. Articulare is in a more inferior position. The total and the upper face height were respectively 3.5 and 2.2 mm greater. At year 3 the total face height and the gonial angle were significantly larger.

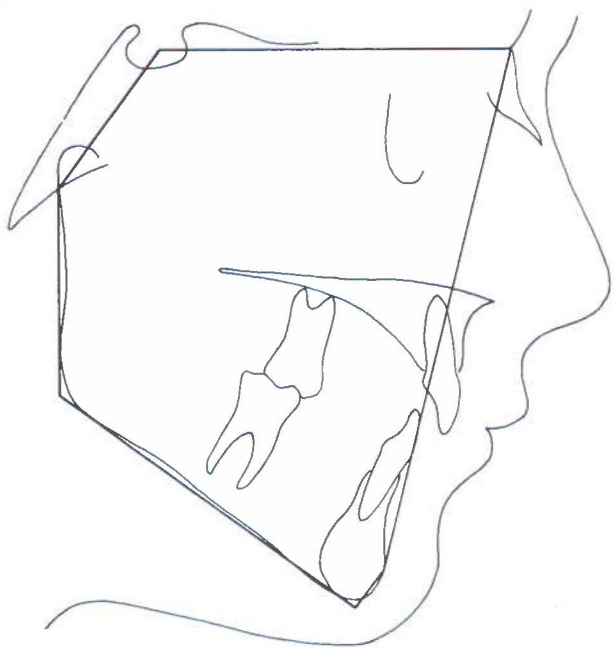
The influence of the X-factor oral habits

No relationship could be demonstrated between the growth variables Y and this X-factor. ∠Ba-S-N was an exception. This angle was 2.2° larger for children with abnormal oral habits than for children without them.
No interpretations can be given for this finding; the literature also fails to provide any suggestions.

The influence of the X-factor temporomandibular joint dysfunction

The influence of this X-factor is recorded in Table 5.8, in which all the regression coefficients with the test statistics are included to give a total picture.

Figure 5.1 Tracing and reference polygon of children without temporomandibular joint dysfunction at year 0.



The Mandibular Plane –MP– of children with temporomandibular joint dysfunction was 2.1° steeper with respect to the Sella–Nasion Plane than it was with the other children, and the gonial angle was 2.7° larger in the former group than in the latter; ∠S–N–Pg was 1.5° smaller. Compared to the chin of children without dysfunction, that of the children with dysfunction was located more dorsally (S–Gn and Ba–Gn both 2.2 mm smaller). A diagonal through the mandible, from Articulare to Gnathion, was 2.3 mm shorter; related to this is the smaller measurement for the projections on OP, the Occlusal Plane. Gol–Pg', the corpus, was 2.5 mm shorter, Ar–Gol, the ramus, 1.3 mm; the exterior contour of the mandible for children with temporomandibular joint dysfunction was thus 2.5+1.3=3.8 mm shorter than for the others.
The results for year 3 corresponded closely with those for year 0. Additionally, the distance between both Gonion's –Gol–Gol– of children with dysfunction was 0.9 mm greater, as was overjet, by 0.6 mm. Compared to year 0, the length of Gol–Pg', the mandibular corpus, was shortened by 0.5 mm less at year 3. Neither for year 0, nor for year 3 could a relationship

Figure 5.2 Reference polygon and the polygon trauma, into which the relevant results of the regression analysis are assimilated.

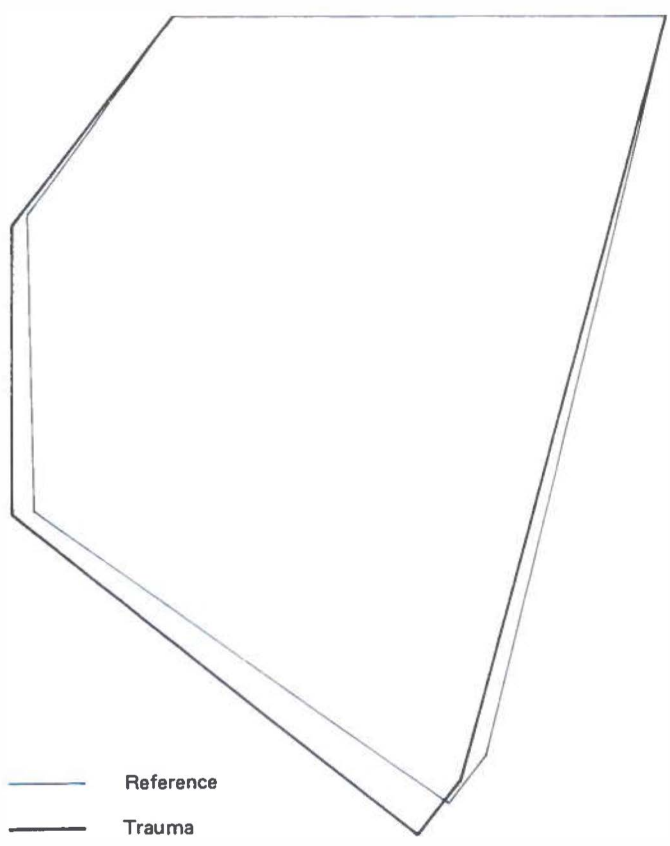


Figure 5.3 Tracing and reference polygon of children without temporomandibular joint dysfunction at year 0.

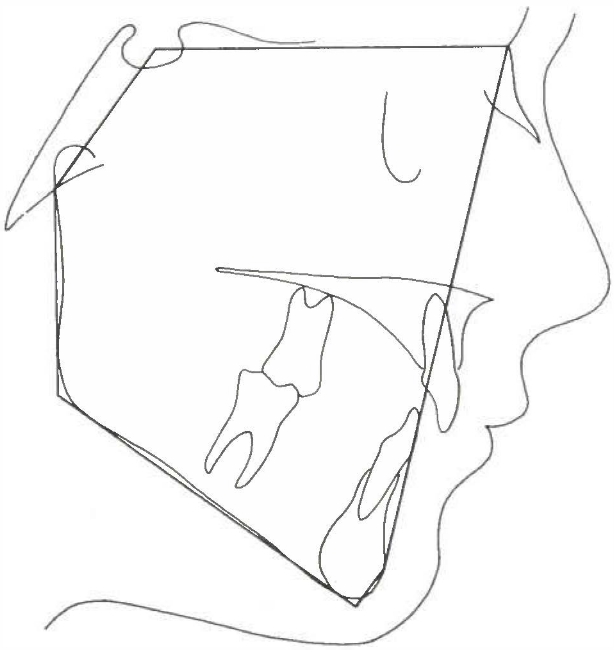
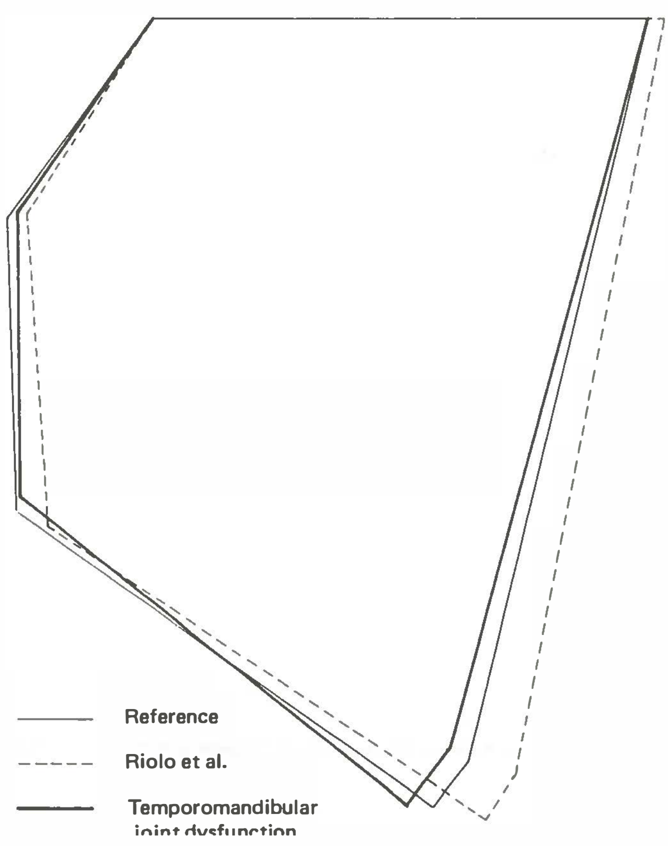


Figure 5.4 The traced polygon is the reference polygon from Figure 5.3. The largest –dotted line– polygon is a construction based on data from Riolo *et al. (section 5.2). The polygon drawn with the thick line is derived from the reference polygon, into which have been assimilated the relevant results of the regression analyses.*



be demonstrated between temporomandibular joint dysfunction and the following growth variables Y: the length of the auricles, maximum mouth opening, the angles ∠SN/OP, ∠SN/RP, ∠RP/OP, ∠S–N–A, ∠Ba–S–N, the Y-axis and the distances TFH, UFH, LFH, S–N, S–Ar, Ar–N, and overbite.

Table 5.8 Regression coefficient and test statistic of the X–factor temporomandibular joint dysfunction in models for the growth variables Y at year 0 and year 3.

	year 0		year 3	
	rc	t	rc	t
Auricle	0.5	0.79	0.8	1.20
Mouth	−0.7	−0.62	−1.8	−1.42
∠ SN/OP	0.4	0.48	0.9	1.02
∠ SN/MP	* 2.1	1.86	2.3	1.98 *
∠ SN/RP	−0.6	−0.60	0.0	0.00
Gonial angle	* 2.7	2.17	2.0	1.60
∠ RP/OP	1.0	1.07	0.9	0.85
∠ S-N-Pg	* −1.5	−2.03	−1.4	−1.76 *
∠ S-N-A	1.1	1.11	0.2	0.22
∠ Ba-S-N	1.1	1.12	0.2	0.24
Y-axis	0.9	1.22	0.9	1.15
TFH	−0.4	−0.42	−0.5	−0.44
UFH	0.5	0.85	1.0	1.38
LFH	−0.9	−1.00	−1.3	−1.38
PFH	* −1.9	−2.00	−2.0	0.00
S-N	−0.2	−0.45	−0.2	−0.38
S-Ar	0.3	0.39	−0.6	−1.06
Ar-N	−0.4	−0.52	−0.6	−0.84
S-Gn	* −2.2	−2.15	−2.0	−1.80 *
Ar-Gn	* −2.3	−2.34	−2.2	−1.97 *
Ba-Gn	* −2.2	−1.96	−2.6	−2.07 *
Gol-Gol	0.2	0.57	0.9	2.03 *
Overjet	0.8	1.50	0.6	1.82 *
Overbite	0.2	0.42	−0.1	−0.23
Gol-Pg'	* −2.5	−3.12	−2.0	−2.31 *
Ar-Gol	* −1.3	−1.75	−1.4	−1.83 *
Pr Ba-Pg/OP	* −2.5	−2.42	−2.6	−2.09 *
Pr Ar-Pg/OP	* −2.4	−2.42	−2.5	−2.15 *

Included are the regression coefficient –rc– with accompanying test statistic –t– in the model where children with temporomandibular joint dysfunction are compared to children without temporomandibular joint dysfunction. The critical value at 102 degrees of freedom is t=1.67 for one–tailed testing. Cases where this value is exceeded are indicated with*.

5.4 Discussion

In the first part of this chapter the reliability of the regression model was illustrated with several examples. In these examples, and in all the analyses which followed, the factors age and sex developed in the same direction and to the same degree as the data derived from the findings of Riolo *et al.* (1974). No documentation exists in the literature on the other X–factors, so that the data obtained for them could not be compared.

It is interesting to note from Table 5.5 that the children who qualified for treatment with an activator at year 0 displayed some distinct differences from those children who were to receive Begg treatment. The proper interpretation of this data is unclear. Several possible reasons for these findings have been discussed in section 3.2.

A difference in results at year 3 and year 0 could point to a differing effect of the two types of treatment. If the measurement for year 3 lags behind that for year 0, it could indicate a decline in growth of the group with Begg, an increase in growth of the group with activator, or a combined effect –that is, the measurement cannot be unambiguously interpreted.

The outcomes of the regression analysis for the factor treatment time cannot be considered without reservations as a measurable treatment result. The orthodontist is, after all, working towards an optimal dental occlusion and an harmonious facial balance, independently of whether or not temporomandibular joint dysfunction exists. The obtained coefficients must apparently be interpreted more as a measure of auxiliary effects of the therapy in question. The maximum mouth opening increases when an activator is worn. This is anatomically conceivable because the activator induces reactive forces in the muscles and ligaments. It is striking that ∠Ba–S–N became more obtuse; but this phenomenon cannot be explained at present.

Angle ∠SN/MP became smaller in the group with Begg; this agrees with the findings of Levin (1975). It is possibly a reaction to the treatment. The overjet is, seen over time, apparently a strongly non–linear phenomenon. A considerable overjet is namely reduced to end to end in the first months of the treatment, and it remains so until the end of treatment. This datum is possibly a measure of the relapse which occurs after every orthodontic treatment.

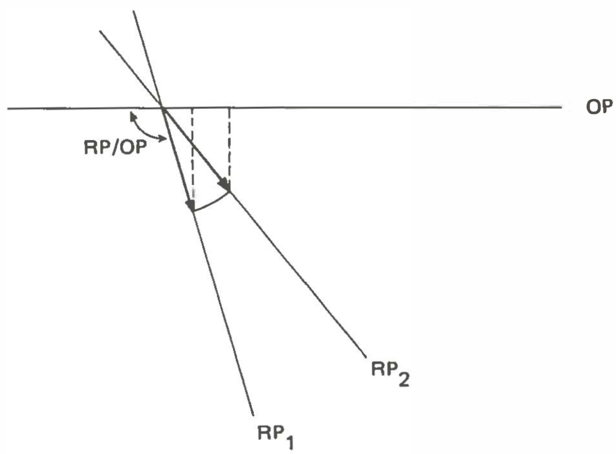
The fact that different significant regression coefficients are constantly noted for activator and Begg therapy underscores the position that these differences are, in fact, caused by the therapy.

Table 5.7 reproduces the influence of trauma to the chin. Although no description was obtained of exactly in what direction and with what force the chin was violently struck, it appears that following a trauma a child's face is elongated. This was especially apparent before the treatment, as can be seen in Figure 5.2.

The number of growth variables Y, which is significantly different when temporomandibular joint dysfunction is present from when it is absent, shows clearly that the X–factor temporomandibular joint dysfunction forms a separate population. Before the orthodontic treatment was begun, the children could already be split into two groups according to craniofacial pattern. A comparison with Riolo *et al.* (1974) shows that both of these groups lag behind in their sagittal development compared to children with balanced profile and normal class I occlusion. A difference was still present after treatment.

Three growth variables Y were used in the computations which are seldom encountered in literature. The relationship between growth and these growth variables Y, which are all computed in relation to the occlusal plane, can now be clarified. The angle between ramus and Occlusal Plane, ∠RP / OP, determines to a certain degree whether or not an increase in length of AR–Gol, the ramus, can improve the occlusal relationship between maxilla and mandible (Figure 5.5).

Figure 5.5 ∠RP/OP

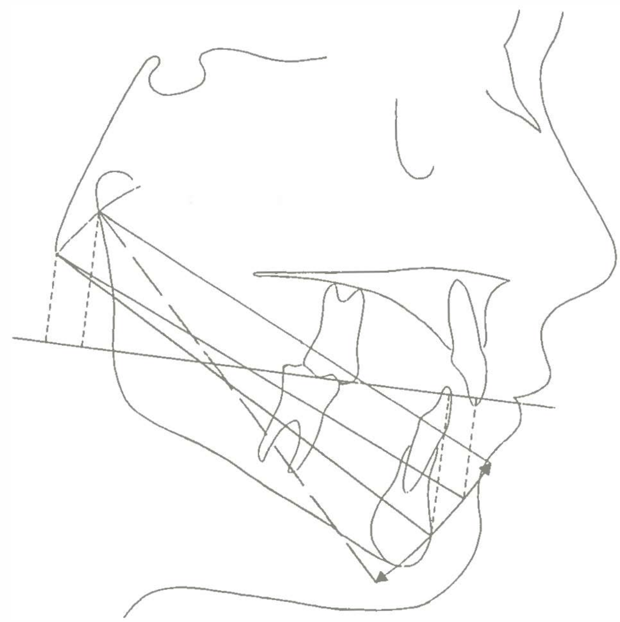


Elucidation.
The length of the arrows along RP_1 and RP_2 is equal. The result of a larger ∠RP / OP, however, is that the projection on OP, and then the movement along OP, is greater for RP_2.

When ∠RP / OP is in a perpendicular position, an increase in length of Ar–Gol will only be accompanied by an increase in the total face height (TFH), and especially an increase in lower face height (LFH). When ∠RP / OP is more acute the increase in length will be expressed in a shifting of the mandible along the Occlusal Plane (Spee 1890). The variables and their projections on the Occlusal Plane can be seen in Figure 5.6.

When the chin describes a circular path, with Ar–Pg as the radius, then the distance Ba–Pg will change as a result of the eccentric position of Ba. Thus, when the

Figure 5.6 The behavior of the projections of Ar–Pg and Ba–Pg on the Occlusal Plane.



angle is rotated from Ar–Pg to the Sella–Nasion Plane, Ba–Pg, rather than a constant Ar–Pg, will increase in length. An enlarged measurement for Ba–Pg accompanied by a measurement for Ar–Pg which remains the same, suggests that the mandible as a whole has shifted in relation to the rest of the skull. Since a shift of the mandible will occur more or less along the Occlusal Plane, the projections of those points of the chin on the Occlusal Plane discussed above, give a better impression of the changes which have occurred.
The point Ba has been chosen with a particular aim in mind. In any explanation of the behavior of projections of landmarks at the chin on the Occlusal Plane under changing circumstances, a point from that plane, located on a relatively stable skull structure, must be chosen as a reference point. Since none of these points posterior to the ramus in the extension of the Occlusal Plane –OP– have been defined, an approach using Basion has been chosen, although the limitations bearing upon its use are well recognized (Ericson and Myrberg 1973).

Two conclusions are now justified:
a. The change in the length of the projections of Ar–Pg and Ar–Gn on OP is an indication that the depth of the dental arch either increases or decreases.
b. The change in the length of the projection of Ba–Pg and Ba–Gn on OP is an indication that the displacement of the chin with respect to the rest of the skull can improve the occlusal relationship of

maxilla and mandible. It is assumed that the observed effects in the mandible will be more extensive than those of the maxilla with respect to the skull.

The calculation of the lengths of the projections of the lines Basion–Pogonion and Articulare–Pogonion on the Occlusal Plane in retrospect makes possible an orthodontic prognosis. The lower dental arch of children with temporomandibular joint dysfunction will be 2.5 mm less deep, barring any further compensations, than the dental arches of children without dysfunction when a 2.5 mm smaller projection of Ar–Pg has been observed in the former group. A projection from Basion–Pogonion which is 2.6 mm smaller in the children with temporomandibular joint dysfunction results from this shortened Ar–Pg.

Chapter 6

Analysis of asymmetries

6.1 Introduction

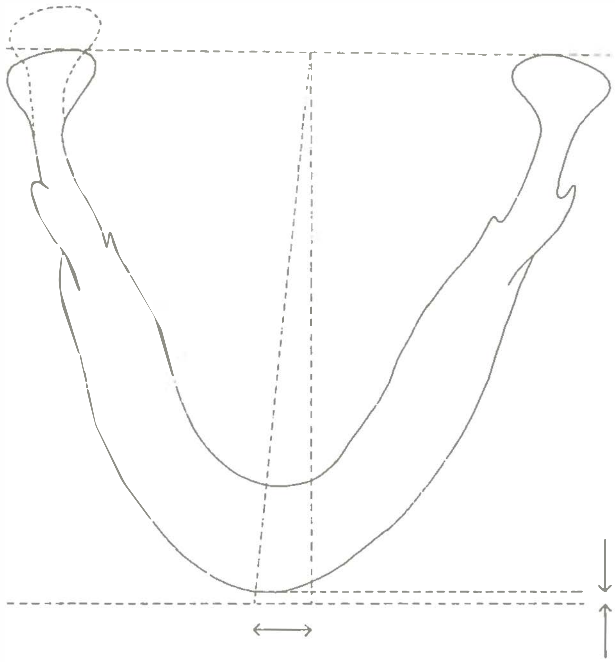
It has been shown in Chapter 5 that the sagittal craniofacial pattern of children with temporomandibular joint dysfunction, as defined in Chapter 3, is different from the pattern of those without such a dysfunction. **It should be remembered at the same time that all the children had an Angle class II, division 1 malocclusion**. When the underdevelopment is the same on both sides of the mandible, the values measured on the lateral cephalogram give a true picture of reality. However, if the problems arise from a more or less unilateral disorder, then their consequences may be only partially identified on the lateral cephalogram. When the distance from Articulare to Pogonion is shorter on one side of a child's skull than on the other, this shortening is only partially visible on the lateral cephalogram because of the form of the mandible. An asymmetry caused by an one-sided disorder will be expressed more accurately with a frontal cephalogram than with a lateral one (Figure 6.1).

A disadvantage of the frontal cephalogram is the absence of reliable landmarks. Additionally, this lack of landmarks, along with other factors, makes the reproducible construction of a plane of symmetry extremely difficult.
This chapter tests whether or not an effect of temporomandibular joint dysfunction is also present in the transversal direction. An analysis of variance is carried out to determine the structure of the growth variables Y on the frontal cephalogram. A regression analysis was done to eliminate the influence of possible intervening factors. Contingency tables were then constructed of the group with temporomandibular joint dysfunction cross-classified with all the findings of the yearly checkups. Finally, all the combinations were tested with the Chi-square test.

6.2 Definition of asymmetry

While carrying out the analyses of all the measurements obtained from the frontal cephalogram and of some of the measurements obtained from the

Figure 6.1 Visibility of a difference in length between left and right mandibular ramus.



A difference in length between left and right ramus causes -in the frontal view- a clearly recognizable deviation of the chin. This difference in length is barely noticeable on the lateral cephalogram.

lateral cephalogram, an extra dimension was added to the X-factor temporomandibular joint dysfunction as defined in section 3.2. The qualification right or left was assigned according to the side where the dysfunction was dominant. Possible differences between analogous left and right growth variables Y could be investigated in this way.
The X-factor temporomandibular joint dysfunction in section 3.2 is composed of three components, namely subjective symptoms, objective symptoms and ADJ. The subjective symptoms were determined from original discoveries of clicking, snapping, crepitation, pain and restriction of movement. The first two symptoms can occur either on the right or left side. ADJ is diagnosed from the Parma radiograph at year 0, 1, 2 and 3 for the left and right joint separately. The objective symptoms comprise only one variable, with the possibility of choosing between right or left sides. When one side was clearly more affected by dysfunction than the other, contradictory findings within the two categories of subjective symptoms or within the four ADJ component parts were never encountered. Combinations which occurred are presented in Table 6.1.

Table 6.1 Combinations which occur when the side on which a symptom appears is taken into consideration along with the original variables which together comprise temporomandibular joint dysfunction.

sub_0 click or snap	sub_0 pain	ob_0	ADJ year 0	ADJ year 1	ADJ year 2	ADJ year 3	Designation of dominant side
0	0	0	0	0	R	B	discarded
0	0	0	R	R	B	B	discarded
0	0	R	0	R	B	B	discarded
0	0	L	0	L	L	B	left dominant
R	0	R	0	0	0	B	right dominant
0	0	0	0	L	B	L	left dominant
0	0	B	0	0	B	B	both sides
B	0	B	0	0	0	0	both sides

0 : no symptoms
B : symptoms on both sides
L : symptoms left side
R: symptoms right side

Three children were eliminated from all the operations described in this chapter. In their cases, more dysfunctions were noted on both sides than on any one dominant side. The combination of a left and right dominant side in one child did not appear.

Definition

The X-factor temporomandibular joint dysfunction is called symmetrical if the component parts sub_0, ob_0 and ADJ (section 3.2) only contain codings for both sides, or 0, which is no dysfunction.

The X-factor temporomandibular joint dysfunction is called left dominant when all the findings from the component parts contain the coding left at least as often as the coding both sides.

The X-factor temporomandibular joint dysfunction is called right dominant when all the findings from the component parts contain the coding right at least as often as the coding both sides.

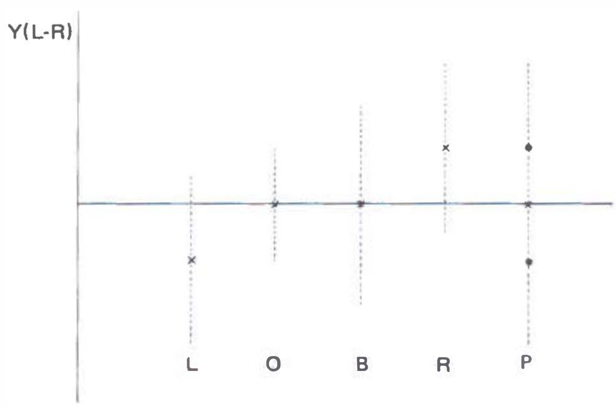
The coding for temporomandibular joint dysfunction always remains 0 if it was originally coded as 0.

It is perhaps interesting to note that no child ever noticed a restricted mouth opening, six felt pain (5%), and twenty perceived a click or snap (18%).

6.3 Analysis of variance and regression analysis

The hypothesis to be tested is that on the side where a temporomandibular joint dysfunction manifests itself, asymmetry of the jaw, possibly due to retarded growth, will be observed. Thus, when there is a dysfunction in the left joint, the left side of the mandible will be retarded, Y(L–R) is $Y_L - Y_R$ will (on the average) be negative (Figure 6.2: L). When there is no dysfunction (0), no asymmetry is present; Y(L–R) will therefore be an average 0 (Figure 6.2: 0). The pattern of means and dispersions can be seen in Figure 6.2.

Figure 6.2 Hypothetical model for mean and variance in populations in accordance with the different dominant sides of the X–factor temporomandibular joint dysfunction.



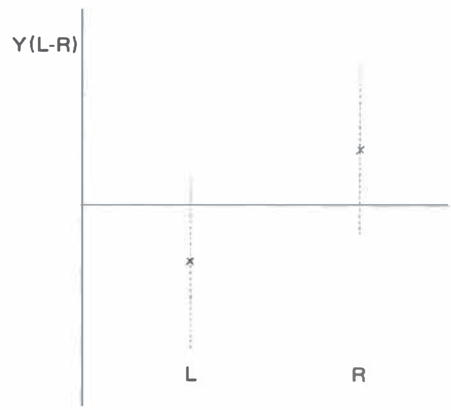
Y(L–R): left growth variable Y minus analogous right growth variable Y. L: deviation is dominant left. 0: no deviation. R: deviation is dominant right. P: deviation one–sided, dominant on the left as often as on the right.

If a dysfunction is bilateral, both mandibular halves will be retarded; often neither side is dominant and Y(L–R) averages 0 (Figure 6.2: B). This is not true if one side takes the lead and lags farther behind in growth than the other. If the dysfunction is more extensive on one particular side, then the difference Y(L–R) will differ from 0; it will be negative if dominant on the left side, and positive if dominant on the right side. If neither side can systematically be assigned the lead in extent of dysfunction, that is, if the left leads in some children and the right leads in others, then an average of 0 will occur anyway. This is because the group that is negative on the average (left in the lead) and the group that is positive on the average (right in the lead) together yield an average of 0. This is expressed by a greater dispersion about the mean 0 (Figure 6.2: P). When the dysfunction is more extensive on the right side, Y(L–R) will be positive on the average (Figure 6.2: R).

Analysis of variance has been used to determine whether or not the situation sketched above actually does occur. In this analysis it is assumed that there is no systematic influence exerted by the remaining X–factors.

Next, the most extreme situation, only a left or only a right dysfunction, is investigated by using a regression analysis. Possible influence of the remaining X–factors is also ruled out here. The hypothesis which is to be investigated is sketched in Figure 6.3.

Figure 6.3 Hypothetical model for mean and variance of the left growth variable Y minus the analogous right growth variable Y in a population with only a left or a right dominant side for temporomandibular joint dysfunction.



L: deviation is dominant left
R: deviation is dominant right

The X–factor is coded 0 for a left dysfunction and 1 for a right dysfunction. The most extreme situation was analysed in this manner. When temporomandibular joint dysfunction has a stronger effect on one side or another, Y(L–R) will be negative on the average where dysfunction is dominant on the left side, and it will be positive on the average when dysfunction is dominant on the right side. In the regression analysis, when there is a "transition" from a left dysfunction to a right dysfunction (X–factor

temporomandibular joint dysfunction from 0 to 1), Y(L–R) is expected to change from negative to positive. This implies a positive correlation.
An analogous line of reasoning can be followed, but with positive and negative interchanged, for differences in angles and for distances which have been measured in relation to an origin which is per definition on the right side. This implies a negative correlation.

Table 6.2 Significant regression coefficients for left or right dominant temporomandibular joint dysfunction.

	year 0	year 3
length of auricle left minus right	+1.5	+1.2
midline upper dental arch	+2.1	+1.8 N
angle pupil line — copper bar	−1.3	−1.8
angle pupil line — interlabial line	−1.4	−2.4

As set up here, the regression coefficient for the length of the auricle should be implicitly positive, and it should be negative for the other three computations.

6.4 Results of the analyses

Analysis of variance

The children are divided into four groups according to whether there is a temporomandibular joint dysfunction on the right side, left side or both sides, or whether one is absent, as defined previously; these groups are considered to be random samples from identical normally distributed populations with equal variance. A test statistic is computed to investigate the hypothesis that the underlying populations also have the same mean. The X-factor temporomandibular joint dysfunction is considered to be a systematic factor. A test statistic is calculated for the growth variables Y from the lateral cephalogram (a separate value has been obtained for measurements of the right and left sides) and for all the growth variables Y from the frontal cephalogram and from the photographs. The Bartlett's test was used to determine whether or not the assumption of identity of variance had been violated. The WESP module involved in the computations is ONEWAYANOVA (De Jonge 1963, 1964; WESP 1976).
The outcomes were unanimous. The only significant difference which could be demonstrated was for the length of the auricles at year 0 and at year 3 (the side with dysfunction was shorter). For none of the others did a single test statistic prove significant. The dispersion of the means about 0 in the group with temporomandibular joint dysfunction on both sides was not noticeably different from the group without dysfunction for any of the growth variables Y.

Regression analysis

The same X-factors, as defined in section 3.2, are used in the regression analysis. The X-factor temporomandibular joint dysfunction is recoded as described in section 6.3. The growth variables Y are the same as those used in the analysis of variance.
The results could likewise demonstrate hardly any significant relationships. Only the significant regression coefficients are reported in Table 6.2.

According to Table 6.2, there is a relationship between the side of dysfunction on the one hand, and the relatively short length of the auricle both at year 0 and at year 3, the slope of the interlabial line and interocclusal bar. The midline of the maxilla was revealed to have been shifted 2.1 mm to the left in the case of complaints on the right side at year 0, for example. This datum is difficult to interpret, and appears to contradict the assumption of retarded growth.

The results of the analyses of variance and the regression analyses provided little inducement for further study in this direction. Nevertheless further analyses were carried out. Clinical observations had clearly shown that "crooked faces" do occur, therefore the same analyses were carried out once more. However this time temporomandibular joint dysfunction was replaced by ADJ (section 3.2 for definition) as the systematic factor. The results of this substitution were analogous to the outcomes described above; no relationship could be demonstrated between the side on which the dysfunction (primarily) manifested itself and the growth variables Y.

Chi-square test

Contingency tables were then made interrelating the X-factor temporomandibular joint dysfunction and ADJ with all the variables from the codebook which had not yet been tested, and which might be related to crookedness. These were the variables:
preferred side of mastication,
slope of interocclusal bar,
deviation of point of the chin,
deviation of the chin when the mouth is opened,
shifting of the mouth on opening,
a difference in the level of the two gonial notches,
degree of movement of both joints when palpated and as recorded on the Parma radiograph,

the asymmetry of the lower part of the face as observed on the frontal cephalogram.
These variables were tested simultaneously per contingency table using the Chi-square test.
The hypotheses on which this testing was based were:
- There is no relationship between temporomandibular joint dysfunction or ADJ and asymmetry of the face.
- No side dominates with respect to this asymmetry; that is, the observed asymmetries occur as often on the right side as on the left.

Before the first hypothesis was tested, all the variables which might be used in testing, and for which a choice of left or right was possible, were recoded to 0 –characteristic absent– and 1 –characteristic present.

The following Chi-square tests were significant:
At year 1, one out of every three children with ADJ showed a difference between the levels of the two gonial notches, compared to one out of every seven children with temporomandibular joint dysfunction. The same relationships existed at year 2 for oscillation of the chin when the mouth was opened or closed. An increased mobility of the joints through palpation at year 1 was observed for one out of five children with ADJ; at every checkup, about two out of five children were observed to have increased mobility of the joints as ascertained on the Parma radiograph.
The variables to be used in testing the second hypothesis were recoded to 0 –only left characteristic– and 1 –only right characteristic. The only significant finding here concerned the difference in the levels of the gonial notches, as clinically determined with interocclusal bars. One out of every three children with ADJ had the left gonial notch located above the right one.

6.5 Discussion

Temporomandibular joint dysfunction can be categorized according to the side on which dysfunction is observed: left dominant – 15 children (14%); right dominant – 16 children (15%); and dysfunction on both sides – 17 children (16%). For ADJ the figures were 9 (8%), 7 (6%) and 6 (5%).
Neither analysis of variance, nor regression analysis, nor Chi-square test could demonstrate a relationship between temporomandibular joint dysfunction and asymmetry of the face as observed either during the clinical examination or from the measuring of cephalograms and photographs.
No connection could be found between the sides where temporomandibular joint dysfunction or ADJ were observed and the following clinical findings:
the preferred side of mastication,
the slope of the interlabial line,
the slope of the interocclusal bar,
the deviation to right or left of the chin and
the deviation to the right or the left of the chin on opening or closing the mouth.

Likewise, no connection could be found with deviations of the lower face, as diagnosed on the frontal cephalogram. A significant difference could be demonstrated clinically between the levels of the two gonial notches in children with ADJ at year 1. This may be an indication that these children react differently to orthodontic treatment than the others. The oscillating of the chin on opening or closing the mouth, which occurs with these children significantly more often after two years, may possibly be the rediscovery of a balance after this therapy has been ended.

It must be concluded that, although asymmetry and progressive asymmetry was occasionally observed in individual children, no significant statistical evidence for a systematic influence of temporomandibular joint dysfunction on symmetry or asymmetry could be substantiated in the material under study.

Chapter 7

Epidemiological aspects

7.1 Introduction

Several epidemiological aspects of temporomandibular joint dysfunction are evaluated in this chapter. Although ADJ is a part of temporomandibular joint dysfunction, the group of children with ADJ has also been evaluated separately. This is because literature indicates that this deformity is often caused by certain predisposing factors. The epidemiological data presented here are only open to limited interpretations because of the nature of the investigatory material available; it should be remembered, for example, that the total sample is composed of children with an Angle class II, division 1 malocclusion, and these children were thus not selected on the basis of temporomandibular joint dysfunction. For this reason the data presented here are not directly comparable to those found in the literature on this topic.

Temporomandibular joint dysfunction is approached from different viewpoints in orthodontic studies. The terms used to denote it are legion, as are the meanings attached to them. Good descriptions of this phenomenon can be found in several textbooks which also explore a number of related aspects; see among others Schwartz (1959), Sarnat (1964) and Boering (1966). Several multidisciplinary reviews have been published in recent years, such as *Temporomandibular Joint-Function and Dysfunction*, Part I (1973), Part II (1974) and Part III (1976) and *The Temporomandibular Joint Syndrome* (1975).

Surprisingly, in all this volume of literature where the concept temporomandibular joint dysfunction is used, it is almost never precisely circumscribed and defined. Several authors have pointed to the existence of a problem in this area. De Boever (1973) writes: (loc.cit.pg.106) "Even in the description and the frequency distribution of the clinical signs and symptoms accompanying functional disturbance of the joints, no complete agreement is found in the literature". According to Carlsson and Öberg, (loc.cit.pg.84) "On the basis of the present knowledge it might be stated that arthrosis is not one disease, but many diseases that end up with a common structural lesion". Finally, Rugh and Solberg (1976) have called for a solution: (loc.cit.pg.26) "More explicit diagnoses need to be identified if definitional problems involving TMJ disorders are to be overcome". Almost all the symptoms described in literature fall under the categorization of symptoms employed in the present study; once more the symptoms are: subjective symptoms, primarily pain, clicking, snapping and restricted mobility of the jaws; objective symptoms, determined by palpating, primarily clicking and snapping; and deformities visible on radiographs. However, nowhere in the literature are these symptoms –individually or as a group– precisely defined as belonging or not belonging to dysfunction; this results in some confusion about the degree to which published results are comparable with findings from the present study. Such a basic lack of clarity concerning definitions leads in turn to contradictory opinions about various aspects of diagnosis and therapy.

Among others Furstman (1965), Bell (1969), Perry (1969), Pietrokovski (1970), Taylor *et al.* (1972), Roth (1973), Shore (1976) and Gausch and Kulmer (1977) believe that the primary factors affecting temporomandibular joint dysfunction are contained in the occlusal relationship, for example as a result of premature contacts. Other researchers cannot support this finding (Ramfjord *et al.* 1971). Boering (1966, 1976[1], 1976[2]) suggests that temporomandibular joint dysfunction is a primary process, and that when the first objective symptoms are determined, a succession of symptoms is likely to follow which –if the control period is long enough– finally leads to deformation of the condyle. Various investigators have observed deviant electromyograms (Freese 1958; Munro 1975; Yemm 1976; Pruim 1977). A possible connection has been suggested between psychological factors and temporomandibular joint dysfunction in some recent works (Schuler 1966; Lupton 1969; Rugh and Solberg 1976). Helkimo (1976) gives a good general survey of what is known about temporomandibular joint dysfunction epidemiology.
In general, the literature indicates that symptoms of temporomandibular joint dysfunction appear after the age of twenty or thirty years; it occurs in women four or five times as often as in men. Boering (1966) however, reports a rather high percentage (26) of young patients twenty years old or younger in a group of 400 patients which he investigated, with symptoms of temporomandibular joint dysfunction.

7.2 Relation between ADJ, temporomandibular joint dysfunction and a number of predisposing factors

Those factors defined in section 3.2 as X-factors are candidates for consideration as possible predisposing factors for temporomandibular joint dysfunction in general, and ADJ in particular. First, the relationship of these factors to ADJ is investigated, then their relation to temporomandibular joint dysfunction.

The following graphs and tables show the relationship between ADJ on the one hand and age, sex, appliance, trauma, oral habits, one-sided mastication, forced bite, attrition and active treatment time on the other. A Chi-square test has been carried out for most of the combinations to discover possible relationships. The critical value selected for testing on a five percent significance level is 3.84; a two-tailed test was used with one degree of freedom.
The relationship between ADJ, age and sex is presented in Figure 7.1; the relationship of ADJ with calcification stage in Figure 7.2.

Table 7.1 shows the relationship between ADJ and sex.

Table 7.1 Contingency table of ADJ and sex.

	sex ♂				♀			
ADJ		↓	→	⇌		↓	←	⇌
absent	39	(80,	45,	35)	48	(76,	55,	42)
present	10	(20,	40,	9)	15	(24,	60,	13)

$\chi^2 = 0.24$ NS

Figure 7.1 The incidence of ADJ in the sample at year 0 as a function of age.
The increase in the number of children with ADJ after about twelve years is striking.

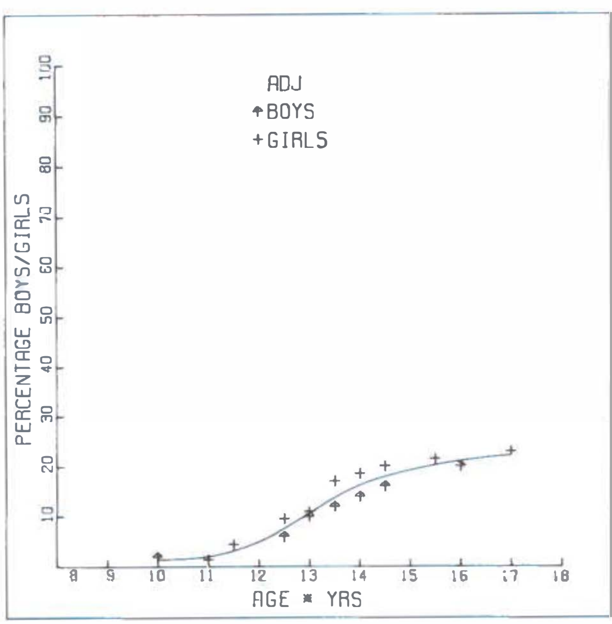
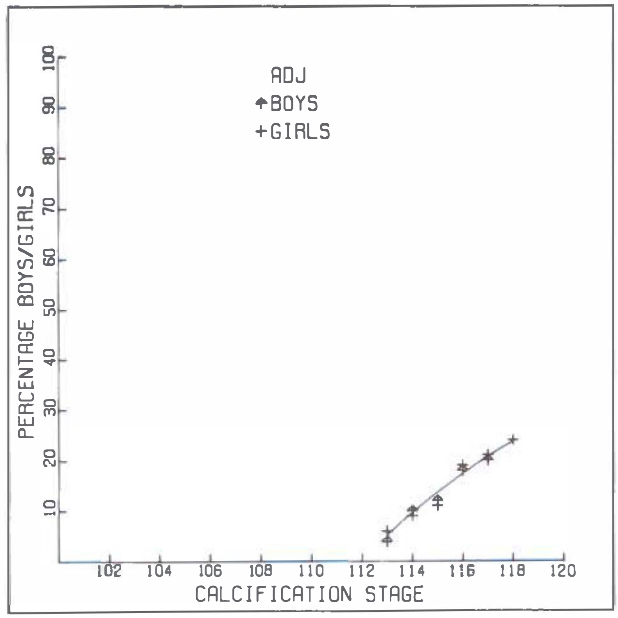


Figure 7.2 The occurence of ADJ in the sample at year 0 as a function of calcification stage.
The increase in the number of children with ADJ after a calcification stage score (Nolla 1960) of about 113 is striking.



Elucidation.
Twenty percent of the boys had ADJ compared to twenty-four percent of the girls; twenty-two percent (9+13) of all the children had ADJ. No relationship could be demonstrated between ADJ and sex.

Table 7.2 illustrates the relationship between ADJ and appliance.

Table 7.2 Contingency table of ADJ and appliance.

	appliance activator				Begg			
ADJ		↓	→	⇌		↓	←	⇌
absent	45	(88,	52,	40)	42	(69,	48,	37)
present	6	(12,	24,	5)	19	(31,	76,	17)

$\chi^2 = 6.02$

Elucidation.
Twelve percent of the children in the group with activator had ADJ, while the percentage was thirty-one in the group with Begg. There was a very

definite relationship between appliance and ADJ. This must apparently be ascribed to the age rather than the choice of appliance; the Begg group was composed of older children. (Figures 7.1 and 7.3). The mean age in the group with activator was eleven years and four months, and it was thirteen years and eight months in the group with Begg.

Table 7.3 shows the relationship between ADJ and trauma.

Table 7.3 Contingency table of ADJ and trauma.

trauma	absent				present			
ADJ		↓	→	⇌		↓	←	⇌
absent	68	(75,	78,	61)	19	(90,	22,	17)
present	23	(25,	92,	21)	2	(10,	8,	2)

$\chi^2 = 2.44$ NS

Elucidation.
A definite form of trauma against the chin could be ascertained for 19% (17+2) children. Of these, 10% proved to be registered in the group with ADJ, while 90% remained without symptoms. This was respectively 25% and 75% for children without trauma. No relationship could be demonstrated between ADJ and a trauma of the chin.

Table 7.4 shows the relationship between ADJ and oral habits. The X-factor oral habits is composed of thumb-sucking, nail-biting and gnashing of teeth.

Table 7.4 Contingency table of ADJ and oral habits.

oral habits	absent				present			
ADJ		↓	→	⇌		↓	←	⇌
absent	34	(74,	39,	30)	53	(80,	61,	47)
present	12	(26,	48,	11)	13	(20,	52,	12)

$\chi^2 = 0.64$ NS

Elucidation.
Abnormal oral habits were observed for 59% (47+12) of the children. (The percentages for the component parts were: thumb- or finger-sucking 10%, nail-biting 50% and gnashing of teeth 9%. There was thus an overlap). Of these, 20% had ADJ, while 80% remained without symptoms. Forty-one percent (30+11) of the children had no abnormal habits, of whom twenty-six percent did and seventy-four percent did not have ADJ. No relationship could be demonstrated between ADJ and oral habits.

Certain results in Chapter 6 contributed to a better understanding of the relationship between preferred side of mastication and ADJ. In that chapter could be seen that no significant relationship could be demonstrated between the side where dysfunction was dominant and the preferred side of mastication. At this point tests will be conducted to determine whether or not a relationship exists between ADJ and one-sided mastication. Table 7.5 shows the relationship between ADJ and one-sided mastication, that is, not alternating between right and left. "One-sided mastication" is coded 0 for symmetrical and 1 for asymmetrical mastication.

Table 7.5 Contingency table of ADJ and the one-sided mastication.

one-sided mastication	symmetrical				asymmetrical			
ADJ		↓	→	⇌		↓	←	⇌
absent	24	(71,	28,	21)	63	(81,	72,	56)
present	10	(29,	40,	9)	15	(19,	60,	13)

$\chi^2 = 1.42$ NS

Elucidation.
At year 0, 69% (56+13) of the children preferred one-sided mastication. Of these, 19% had ADJ and 81% remained without symptoms. Thirty percent (21+9) did and 71% did not have ADJ. No relationship between ADJ and the preferred side of mastication could be demonstrated.

The forced occlusion caused by a forced bite is combined with the forced one-sided mastication caused by loss of buccal teeth to form one variable. This is coded 0 if there is no forced bite and symmetrical mastication is possible; in all other cases it is coded 1. This combination seemed acceptable because both factors can contribute to involuntary loading of the joint. Table 7.6 shows the relationship between ADJ and this variable.

Table 7.6 Contingency table of ADJ and forced bite and / or forced one–side mastication.

forced occlusion	absent				present			
ADJ		↓	→	⇌		↓	←	⇌
absent	78	(78,	90,	70)	9	(75,	10,	8)
present	22	(22,	88,	20)	3	(25,	12,	3)

$\chi^2 = 0.06$ NS

Elucidation.
At year 0 there was a forced bite and/or forced one–sided mastication in 11% (8+3) of the children. Of these, 25% had ADJ and 75% did not. There was no interference in 90% (70+20) of the children. Of these, 22% did, and 78% did not have ADJ. No relationship could be demonstrated between this variable and ADJ.

Table 7.7 presents the relationship between ADJ and attrition.

Table 7.7 Contingency table of ADJ and attrition.

attrition	absent				present			
ADJ		↓	→	⇌		↓	←	⇌
absent	68	(76,	78,	60)	19	(83,	22,	17)
present	21	(24,	84,	19)	4	(17,	16,	4)

$\chi^2 = 0.41$ NS

Elucidation.
At year 0, attrition was reported for 21% (17+4) of the children. Of these, 17% had ADJ and 83% did not. Attrition was not visible for 79% (60+19). Of these, 24% did and 76% did not have ADJ. No relationship could be demonstrated between ADJ and attrition.

To determine whether or not a relationship existed between the active treatment time and ADJ, the children were divided into two groups, one with and one without ADJ. The hypothesis that the mean active treatment time of the two groups was equal was tested with Student's t–test, both for the group with activator and for the group with Begg appliance. The result was t=0.21 with 49 degrees of freedom for the group with activator and t=1.31 with 59 degrees of freedom for the group with Begg. The critical value for two–tailed testing was t=2.00. Thus, no significant relationship could be demonstrated between ADJ and active treatment time with either activator or Begg. This lack of a relationship can perhaps be explained as follows: The presence or absence of ADJ was not taken into account during orthodontic treatment, in the sense that all the children were treated until an acceptable dental occlusion was achieved. The treatment time required to reach that goal was the same for children with and without ADJ.

From Table 7.1 and its computed Chi–square test statistic it must be concluded that ADJ demonstrates no preference for either sex. From the Tables 7.3 to and including 7.7, and from their accompanying Chi–square test statistics can be inferred that ADJ has no significant relationship with trauma, abnormal oral habits, one–sided mastication, forced bite or attrition.

An identical picture as that for ADJ results when contingency tables are constructed and Chi–square and Student's t–test statistics are computed for temporomandibular joint dysfunction. None of the temporomandibular joint dysfunction relationships are significant, except the one with the appliance. The relationship between temporomandibular joint dysfunction and age and sex are presented in Figure 7.3; the relationship with calcification stage in Figure 7.4.

The findings allow the following statements:
In the group of children with Angle class II, division

Figure 7.3 The incidence of temporomandibular joint dysfunction in the sample at year 0 as a function of age. The increase after about ten years is striking.

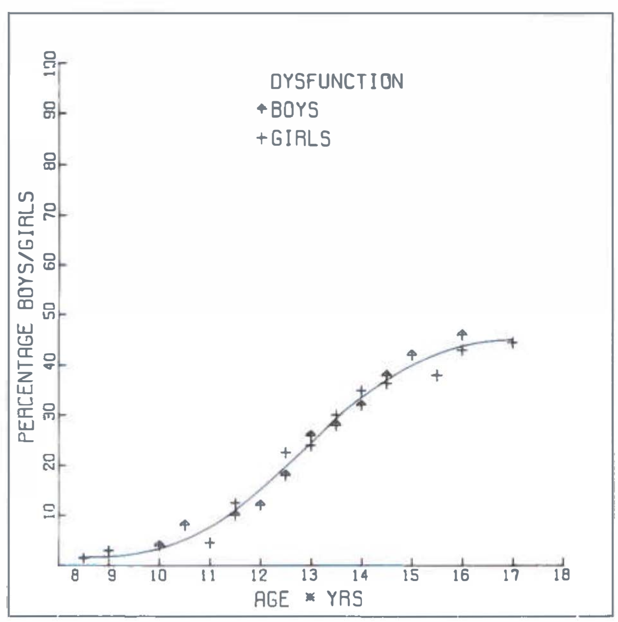
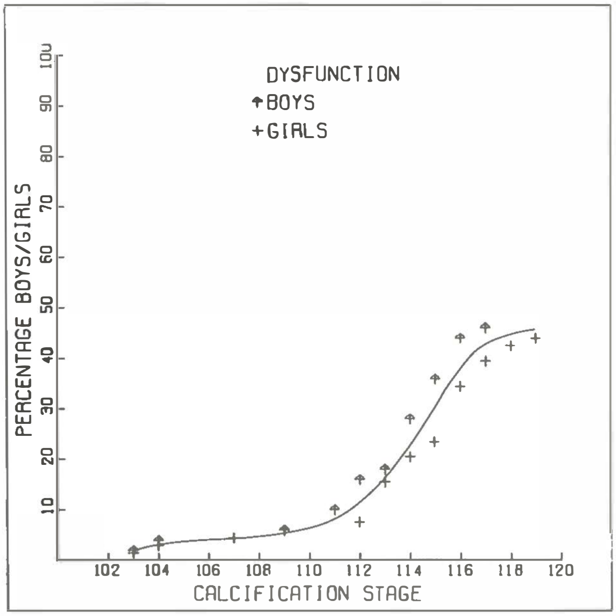


Figure 7.4 The incidence of temporomandibular joint dysfunction in the sample at year 0 as a function of calcification stage.
The increase after a score of about 105 is striking.



1 malocclusion, twenty-four percent had ADJ and fourty-six percent had temporomandibular joint dysfunction; both syndromes have been defined in section 3.2. The craniofacial pattern of children displaying one of these two deviations differed in certain aspects from the pattern of those children with an Angle class II, division 1 malocclusion, but without dysfunction. The two deviations demonstrated no preference for either of the two sexes. A trauma of the chin was found in nineteen percent of the children. Ten percent sucked thumb or finger, and fifty percent bit their nails, though this was often denied by the children. No relationship could be demonstrated with the possible predisposing factors which were investigated.

7.3 Temporomandibular joint dysfunction, ADJ and asymmetries

Very few relationships could be demonstrated between the X-factors and temporomandibular joint dysfuntion and ADJ; from an extensive computer output of contingency tables only a few relationships proved to be significant with a Chi-square test. The significant tests were recorded in Chapter 6.

Thirty-five percent of the children preferred to masticate on one side; for forty percent this was the left side, and for sixty percent the right side.
At year 0, the slope of the interlabial line and of the interocclusal bar was horizontal as often as it was tipped; the levels of the two gonial notches were equal in height as often as they were uneven in height. This changed somewhat each year, until at the end of the third year only 20% symmetrical cases and 80% asymmetrical cases were noted. When the interlabial line was not horizontal it rose toward the right in 40% of the children and toward the left in 60%. The interocclusal bar, on the other hand, rose equally as many times toward the right as it did toward the left. The left gonial notch of the majority of children was higher than the right one. This percentage rose gradually from 70% at year 0, to 90% at year 3. At year 0 to and including year 3 the chin deviated with 15% to the left or right; the open-close cycle was unstable or shifting in 30% of the children, and an increased mobility was palpated in 35% of the cases. An asymmetry of the lower face was observed on the frontal cephalograms of 20% of the children. No explanation for these asymmetries has been found in this study.
Increased mobility (section 2.4.3 for definition) was observed for 40% of the children on the Parma radiograph; mobility was increased significantly less often for children with ADJ than for children without it.

The ratio between increased mobility and normal mobility as ascertained from the Parma radiographs was about two to three. This finding indicates the need for an improvement of the definition of normal mobility to cover a situation where the condyle is located on or just beyond the highest point of the articular tubercle.

Chapter 8

Analysis of the component parts of temporomandibuar joint dysfunction using the regression model

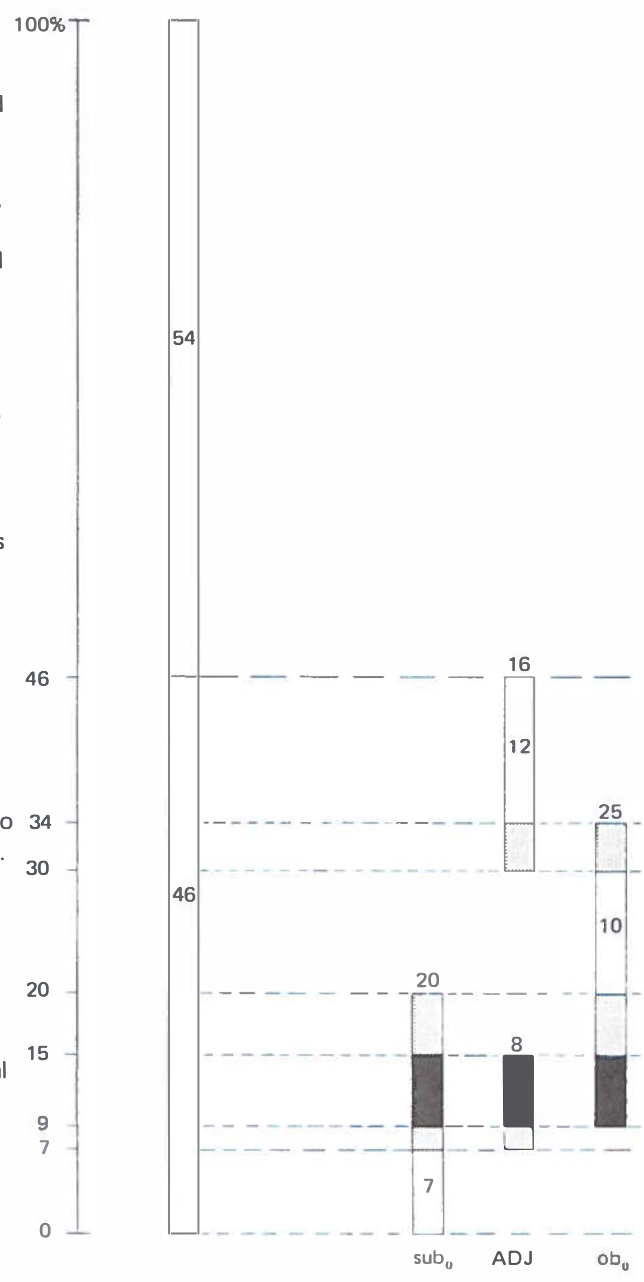
8.1 Introduction

In this chapter the relationship between craniofacial pattern and the component parts of temporomandibular joint dysfunction is discussed. The outcomes from Cohen's unweighted kappa (κ) tests and the findings obtained in Chapters 5, 6 and 7 were an inducement for making this detailed analysis; that is, these results were consistently different from what was to be expected according to the literature. The regression model described in Chapter 5 is also applied here, using the same assumptions. At this point it was decided that the direction under the alternative hypothesis could no longer be predicted with certainty, and testing was therefore always two-tailed.
The X-factor temporomandibular joint dysfunction and the other X-factors, as well as the growth variables Y are defined in Chapter 3.
The relationship is investigated between the component parts and the growth variables Y at year 0 (8.4.1). This analysis is important, because there has been no orthodontic treatment at that point. A follow-up investigation of the relationship between component parts and the growth variables Y of year 3 (8.4.2) can shed light on how these relationships change over time.

8.2 Cohen's unweighted kappa (κ)

Various symptoms have been combined in Chapter 3 to form one X-factor temporomandibular joint dysfuction. This was done in part because of the nature of the operations which were to be carried out with this X-factor. When several closely related X-factors are added to a regression analysis, it is no longer clear which part of the variance of the growth variable Y is explained by which individual X-factor. In addition, the literature ascribes all the symptoms to the same clinical phenomenon.
The X-factor temporomandibular joint dysfunction comprises precise descriptions of a number of symptoms assigned to the phenomenon, but it gives no insight into the mutual relationships which may exist among these component symptoms. The different components of temporomandibular joint dysfunction overlap each other within the group of children studied. Some children, for example are included both in the group with subjective symptoms and in the group with ADJ; others belong both to the group with objective symptoms and to the group with ADJ (Figure 8.1). For still others, subjective symptoms were reported at year 0 which could also be objectively corroborated. An X-ray of a deformed condyle produces strong suspicions that subjective and objective symptoms were or are also present.
Figure 8.1 (and Figure 3.1 earlier) has been

Figure 8.1 Constructing the X-factor temporomandibular joint dysfunction from the component parts.



constructed from various contingency tables with the aim of gaining an insight into the overlapping of these symptoms.

Figure 8.1 gives a good insight in graphic form into the formation of the X-factor temporomandibular joint dysfunction from the separate components. The degree of overlap is also pictured. Yet, Figure 8.1 does not provide any definitive explanation of the mutual relationships of these components. The observed overlapping can be due to chance.

According to the literature, some subjective and objective symptoms can be considered as precursors of degenerative process in the joint. In the course of time, a deformity which is visible on radiographs will develop in a number of the children with these symptoms (Boering 1966, 1976[1], 1976[2]). On the other hand, the deformed joints are described as being accompanied by symptoms identical to those which have been characterized under the categories subjective and objective (Boering 1966; Worth 1975). A significant relationship can therefore be expected to exist between sub$_0$, ob$_0$ and Rö$_0$.
The relationship between sub$_0$, ob$_0$ and ADJ should be even stronger, since ADJ, as defined in section 3.2.1, is characterized by deformities seen on the X-ray which, according to the literature, were preceded by subjective and objective symptoms.

The percentage of the total number of children that displays each of the three component parts of the X-factor temporomandibular joint dysfunction is vertically plotted for each component. The percentages are also given in numbers.
Forty-six percent of the children had temporomandibular joint dysfunction. From these, 45% had subjective symptoms at year 0, 55% had objective symptoms at year 0, and ADJ was diagnosed for 49%. Thus (45+55+49)%-100%=49% of the symptoms were reported more than once.

The dysfunction was composed of
16% purely subjective symptoms,
4% subjective symptoms and ADJ,
14% subjective and objective symptoms and ADJ,
11% subjective and objective symptoms,
22% purely objective symptoms,
8% objective symptoms and ADJ,
25% ADJ.

The unweighted kappa has been used to test the agreement among the components of the definition for temporomandibular joint dysfunction (Cohen 1968). A test statistic which is normally distributed can be derived from the computed kappa. In this way it is tested whether or not the diagonal of a 2x2 table, which indicates agreement (corresponding scores for having or not having a characteristic, or 1-1 and 0-0), can have occurred by chance. The two scores outside this diagonal must also be taken into account.
The null hypothesis in this case is: there is no relationship between sub$_0$ or ob$_0$ on the one hand and Rö$_0$ or ADJ on the other. The expectation is that this null hypothesis for Rö$_0$ will have to be rejected, and that for ADJ will be even more certainly untenable. The results of the computations are recorded in Table 8.1.

Table 8.1 Testing for a relationship among the component parts of the X-factor temporomandibular joint dysfunction.

	Rö$_0$	
sub$_0$	absent	present
absent	79	10
present	15	8
		112

	Rö$_0$	
ob$_0$	absent	present
absent	76	8
present	18	10
		112

	ob$_0$	
sub$_0$	absent	present
absent	73	16
present	11	12
		112

	ADJ	
sub$_0$	absent	present
absent	73	16
present	14	9
		112

	ADJ	
ob$_0$	absent	present
absent	70	14
present	17	11
		112

Relationship	κ	Test statistic
sub$_0$-Rö$_0$	0.26	1.78
ob$_0$-Rö$_0$	0.30	2.21
sub$_0$-ob$_0$	0.32	2.47

Relationship	κ	Test statistic
sub$_0$-ADJ	0.21	1.55 NS
ob$_0$-ADJ	0.24	1.87

At year 0, a significant relationship proved to exist between the subjective and objective symptoms and deformities observed on the radiograph. The number of deformities observed on the radiograph increases in time (section 3.2.1), but the relationship with subjective and objective symptoms diminishes.

Table 8.1 demonstrates, moreover, that the children for whom a deformed condyle was not observed until the later years of the study, did not all come from the group with subjective or objective symptoms. This is an important discovery, since it means that these symptoms were not harbingers of the ADJ diagnosed in this study.
In Chapter 5 it was shown that by using the X-factor temporomandibular joint dysfunction a group of children could be isolated from the total group of children with an Angle class II, division 1 malocclusion; this group with temporomandibular joint dysfunction had a different craniofacial pattern compared to children without such dysfunction. Using the outcomes from Table 8.1, the group of children with temporomandibular joint dysfunction can be further subdivided, this time on the basis of the components sub_0, ob_0 and ADJ. Whether or not the craniofacial patterns within these sub groups are different will now be investigated. This is the primary reason why the testing of separate components was begun. Since it was seen in Chapter 5 that the regression model worked well for the analysis of temporomandibular joint dysfunction, it was decided to use this method for the analysis of its components as well.

8.3 The variables in the model

As in Chapter 5, an effect was sought in the sagittal direction. Measurements on lateral cephalograms were used to demonstrate this effect, while taking into account the reduction of variables described in that chapter. Additionally, as a result of the conclusions from Chapter 6, the mean was computed and retained for all those components for which a separate measurement variable was reported for the left and right sides.
The growth variables Y and the X-factors are circumscribed in Chapter 3. Instead of using the X-factor temporomandibular joint dysfunction, the component parts have now been used separately, as they are defined in Chapter 3.

For fundamental reasons changes have been introduced in the choice of the description "characteristic present" and "characteristic absent". When an insight is sought into the differences in growth variables Y between children with some defined characteristic and children without it, both groups can simply be compared with one another. Knowledge of the consequences attached to the presence or absence of that characteristic is increased in the process of comparison. It is in this way that temporomandibular joint dysfunction was studied in Chapter 5. Rather than forming groups, the regression analysis considers the whole population simultaneously, as a technical refinement designed to eliminate the disturbing influences of variables such as age, sex, etc.
The reasoning followed above, though correct enough in itself, does not always apply, as can be seen in Figure 8.1. There it can be seen that some of the children with subjective symptoms also display objective symptoms and deformities on the Parma radiographs. However, if the group with subjective symptoms were constantly compared with "the rest" –with all the other children– that same Figure 8.1 would indicate that there are also children in this "rest" group with objective symptoms and a deformity on the X-ray.
Which symptoms can be seen as forming a pattern without fear of misrepresentation? The only thing that can be said about subjective and objective symptoms belonging together is that the presence of one does not exclude the presence of the other. After all, the click or snap determined from palpating may be the same click or snap which the child reported when questioned. An overlap of subjective and objective symptoms is thus plausible. For ADJ, however, the case is different. A diagnosis of ADJ reached from studying the Parma radiograph of the temporomandibular joint is based on the determination of a clearly deformed joint. It is plausible that a structurally and/or morphologically afflicted joint can be responsible for subjective and objective symptoms. Thus when studying relationships between subjective and objective symptoms, the possibility of their belonging to ADJ must be eliminated. Conversely, these subjective and objective symptoms most probably form a part of ADJ, but they will have no influence on the effect of ADJ on the craniofacial pattern.
Therefore the following statements must be introduced.

In this and in the following chapters, "purely subjective symptoms" and "purely objective symptoms" will be understood to be those which occur without the simultaneous occurrence of ADJ. The children who serve as a reference group in the following analyses are the children without temporomandibular joint dysfunction. It must be emphasized once more that the children without temporomandibular joint dysfunction do belong to a population of children having a class II, division 1 malocclusion.

Since in this and the following chapters an insight is sought into the effect of the symptoms separately, the technical refinements described above are systematically employed. The X-factor in question is coded 0 when temporomandibular joint dysfunction is absent, and 1 for "characteristic present". For the regression analysis, this meant that a number of children were eliminated at each stage as a result of the overlap described above.

To summarize: regression analysis is again carried out on the same growth variables Y as in Chapter 5, along with the same X–factors, with the exception of the X–factor temporomandibular joint dysfunction. New factors which replace this X–factor temporomandibular joint dysfunction are "purely subjective symptoms", "purely objective symptoms", and "ADJ" as defined previously.

8.4 The results

Because the results obtained in this part of the study have considerable import for the final conclusions, the presentation has been made as comprehensive as possible. The exhaustive list of growth variables Y with their accompanying regression coefficient (rc), t–value and number of degrees of freedom have been given whenever necessary. At the same time the t–value is given for which the null hypothesis may be rejected with two–tailed testing; cases where the critical value has been exceeded are indicated with **. A tracing has been constructed to present the results graphically. This tracing (Figure 8.2) is drawn by hand through the means of all the cephalometric values from the children without temporomandibular joint dysfunction. The connection of a number of these mean cephalometric values forms the reference polygon. The difference between the derived polygon and the reference polygon is determined by assimilating the regression coefficients of the respective X–factor into the reference polygon. Additionally, a polygon –dotted line– which can be derived from data from Riolo *et al.* (1974) is constructed (Chapter 5). All three polygons are presented in one figure superpositioned along Sella–Nasion registered on Sella.

8.4.1 Relationships between the component parts of the X–factor temporomandibular joint dysfunction and the growth variables Y at year 0

The results of the regression analyses for the growth variables Y at year 0 are recorded in Tables 8.2 to and including 8.4, and Figures 8.2 to and including 8.5; children with purely objective symptoms, purely subjective symptoms and ADJ respectively are compared to children with no temporomandibular joint dysfunction.

Table 8.2 shows no significant regression coefficients, with the exception of ∠S–N–A. This measurement is, surprisingly enough, **not** significant for children with purely subjective symptoms or ADJ. The variance within the measurements of the growth variables Y at year 0, therefore, cannot be partially explained by the X–factor objective symptoms. Tables 8.3 and 8.4 are discussed comparatively.

Table 8.2 Regression coefficient and test statistic for the X–factor purely objective symptoms in models for the growth variables Y at year 0.

	year 0	
	rc	t
Auricle	0.2	0.23
Mouth	−0.3	−0.21
∠ SN/OP	0.8	0.57
∠ SN/MP	1.3	0.82
∠ SN/RP	0.4	0.29
Gonial angle	1.8	1.09
∠ RP/OP	0.5	0.35
∠ S-N-Pg	−1.1	−1.04
∠ S-N-A	** −3.0	−2.70
∠ Ba-S-N	2.0	1.45
Y-axis	1.3	1.15
TFH	0.2	0.11
UFH	1.7	1.80
LFH	−0.9	−0.71
PFH	−1.3	−0.96
S-N	−1.1	−1.44
S-Ar	1.3	1.14
Ar-N	−0.7	−0.66
S-Gn	−1.8	−1.19
Ar-Gn	−1.1	−0.79
Ba-Gn	−1.6	−0.96
Gol-Gol	0.1	0.19
Overjet	0.5	0.63
Overbite	−0.1	−0.21
Gol-Pg′	−1.4	−1.18
Ar-Gol	−0.7	−0.66
Pr Ba-Pg/OP	−2.2	−1.43
Pr Ar-Pg/OP	−1.6	−1.12

Included are the regression coefficient –rc– with accompanying test statistic –t– in the model where children with purely objective symptoms at year 0 are compared to children without temporomandibular joint dysfunction. The critical value at 69 degrees of freedom is t=1.99 for two–tailed testing. Cases where this value is exceeded are indicated with**.

Significant regression coefficients are recorded more often for children with ADJ than for children with purely subjective symptoms. In addition, the absolute value of most of the regression coefficients is greater for the children with ADJ. It is clear that the results of the regression analyses with temporomandibular joint dysfunction as X–factor (Chapter 5) are based on the influence of both of these symptoms. Yet there are several notable differences.

Table 8.3 Regression coefficient and test statistic for the X–factor purely subjective symptoms in models for the growth variables Y at year 0.

	year 0	
	rc	t
Auricle	1.1	1.14
Mouth	−0.3	−0.18
∠ SN/OP	−0.4	−0.31
∠ SN/MP	0.6	0.33
∠ SN/RP	** −3.3	−2.29
Gonial angle	3.6	1.97
∠ RP/OP	** 2.9	2.15
∠ S-N-Pg	−0.5	−0.38
∠ S-N-A	−0.4	−0.26
∠ Ba-S-N	1.6	0.99
Y-axis	0.6	0.49
TFH	−1.5	−0.96
UFH	−0.2	−0.23
LFH	−1.3	−0.93
PFH	−0.5	−0.30
S-N	0.2	0.24
S-Ar	** 3.4	2.60
Ar-N	0.7	0.56
S-Gn	−2.4	−1.42
Ar-Gn	−2.4	−1.48
Ba-Gn	−2.1	−1.08
Gol-Gol	−0.6	−0.93
Overjet	0.9	1.03
Overbite	1.1	1.54
Gol-Pg'	** −3.1	−2.31
Ar-Gol	−1.4	−1.18
Pr Ba-Pg/OP	−1.4	−0.82
Pr Ar-Pg/OP	−1.1	−0.71

Included are the regression coefficient –rc– with accompanying test statistic –t– in the model where children with purely subjective symptoms at year 0 are compared to children without temporomandibular joint dysfunction. The critical value at 67 degrees of freedom is t=1.99 for two–tailed testing. Cases where this value is exceeded are indicated with **.

Table 8.4 Regression coefficient and test statistic for the X–factor ADJ in models for the growth variables Y at year 0.

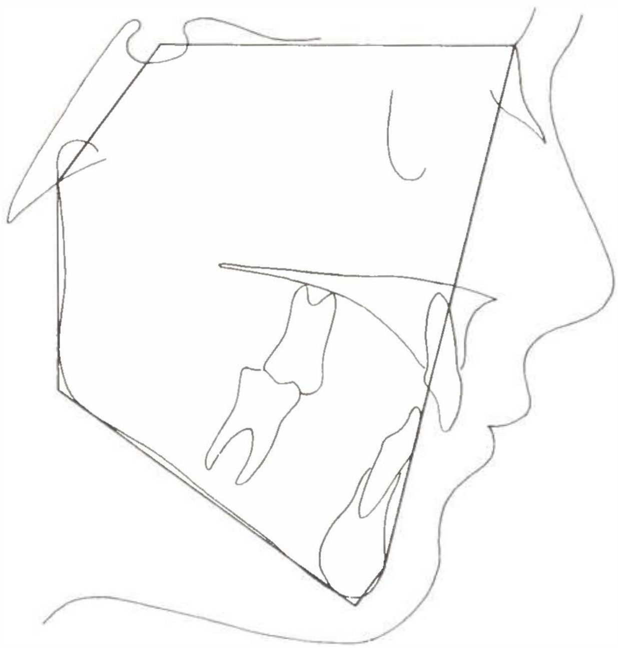
	year 0	
	rc	t
Auricle	0.7	0.91
Mouth	−1.0	−0.76
∠ SN/OP	0.7	0.66
∠ SN/MP	2.7	1.88
∠ SN/RP	0.3	0.23
Gonial angle	2.3	1.39
∠ RP/OP	0.5	0.39
∠ S-N-Pg	** −2.2	−2.32
∠ S-N-A	−1.4	−1.34
∠ Ba-S-N	0.9	0.80
Y-axis	0.4	0.45
TFH	−0.9	−0.71
UFH	0.3	0.32
LFH	−1.4	−1.19
PFH	** −3.4	−2.87
S-N	0.1	0.20
S-Ar	−1.2	−1.69
Ar-N	−0.7	−0.74
S-Gn	** −3.1	−2.39
Ar-Gn	** −3.1	−2.53
Ba-Gn	−2.7	−1.92
Gol-Gol	0.6	1.32
Overjet	1.3	1.93
Overbite	0.0	0.09
Gol-Pg'	** −2.9	−2.72
Ar-Gol	−1.7	−1.70
Pr Ba-Pg/OP	** −2.9	−2.23
Pr Ar-Pg/OP	** −3.2	−2.54

Included are the regression coefficient –rc– with accompanying test statistic –t– in the model where children with ADJ are compared to children without temporomandibular joint dysfunction. The critical value at 78 degrees of freedom is t=1.99 for two–tailed testing. Cases where this value is exceeded are indicated with **.

It was interesting to note that in the angular measurements of the mandible the significant regression coefficients of children with purely subjective symptoms were related to the Ramal Plane, RP; the gonial angle was barely insignificant. For the children with ADJ, the angle ∠S-N-Pg was about 2° smaller, the PFH was 3.4 mm smaller, S-Gn, Ar-Gn, Gol-Pg' (corpus), and the projections of Ba-Pg and Ar-Pg on OP were about 3 mm smaller than for children without temporomandibular joint dysfunction; for children with purely subjective symptoms significant regression coefficients were noted for Gol-Pg' (corpus), which was 3 mm smaller and for S-Ar which was 3.4 mm longer than for children without temporomandibular joint dysfunction.

The difference between children with purely subjective symptoms and children with ADJ was so striking that these two groups were isolated and compared with one another. The results of the regression analyses of the growth variables Y at year 0, in which the children with purely subjective symptoms are compared with children with ADJ, are recorded in Table 8.5. An X–factor has been drawn up for this purpose, coded 0 for purely subjective symptoms and 1 for ADJ.

Figure 8.2 Tracing and reference polygon for children without temporomandibular joint dysfunction at year 0.



A striking observation from Table 8.5 and Figure 8.6 is that Articulare occupies significantly different positions in the two cases. The remaining significant values agreed with this finding, so that an anatomical significance has to be assigned to this difference in position. Comparison with the regression coefficient for S–Ar in Tables 8.3 and 8.4 revealed that Articulare in children with ADJ lay anterosuperior, and that of children with purely subjective symptoms lay inferoposterior, both in relation to the position of Articulare in children without temporomandibular joint dysfunction. This situation is illustrated in Figure 8.6. This topic will be explored more deeply in section 10.3.

Figure 8.3 Superpositioning of the reference polygon at year 0, the polygon derived from it for children with purely subjective symptoms, and the polygon derived from data from Riolo *et al. (Chapter 5).*

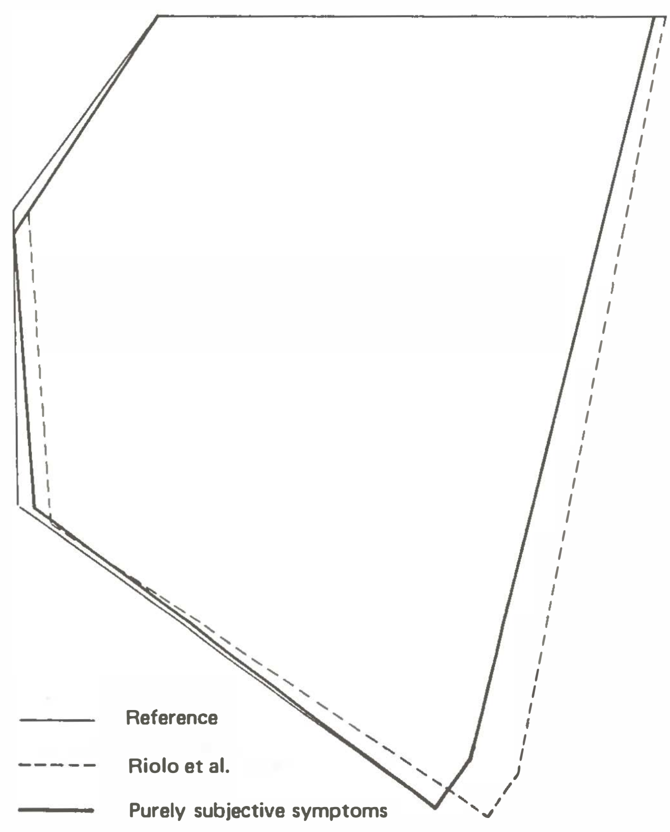


Figure 8.4 Tracing and reference polygon for children without temporomandibular joint dysfunction at year 0.

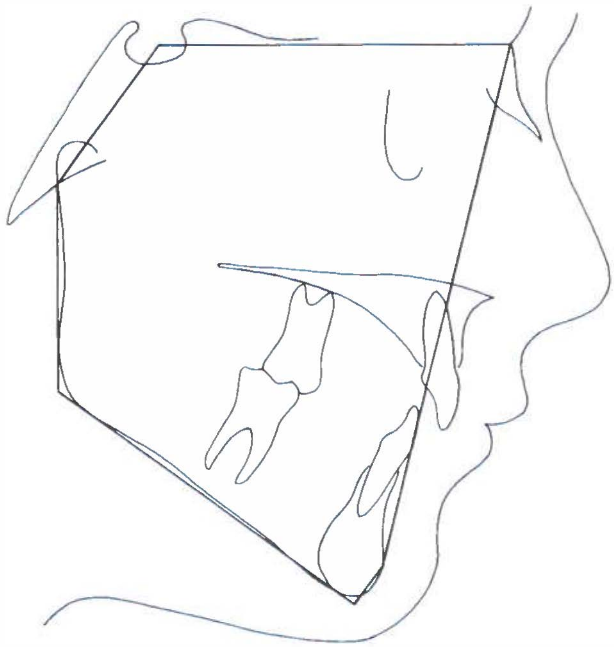


Figure 8.6 Detail of the position of Articulare as it can be inferred from Table 8.5.

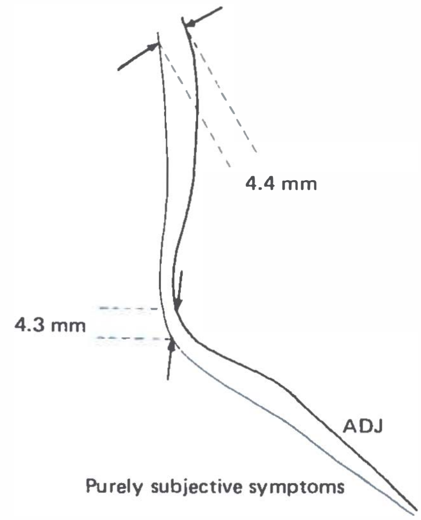


Figure 8.5 Superpositioning of the reference polygon at year 0, the polygon derived from it for children with ADJ, and the polygon derived from data from Riolo *et al. (Chapter 5).*

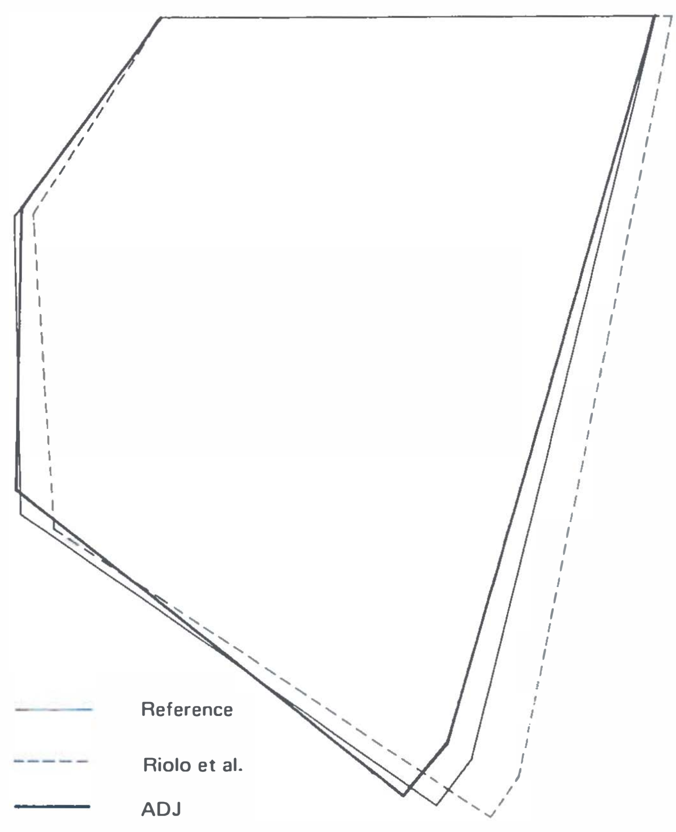


Table 8.5 Regression coefficient and test statistic for the X–factor which was coded 0 for purely subjective symptoms and 1 for ADJ in models for the growth variables Y at year 0.

	Sub_0 × ADJ	
	rc	t
Auricle	−1.3	−1.04
Mouth	−0.5	−0.23
∠ SN/OP	1.1	0.89
∠ SN/MP	1.0	0.47
∠ SN/RP	** 4.9	2.56
Gonial angle	−3.9	−1.65
∠ RP/OP	** −3.9	−2.11
∠ S-N-Pg	−0.9	−0.73
∠ S-N-A	−0.2	−0.12
∠ Ba-S-N	−0.2	−0.11
Y-axis	−0.9	−0.63
TFH	−2.2	−1.57
UFH	−0.5	−0.44
LFH	−1.9	−1.22
PFH	** −4.3	−2.99
S-N	−0.7	−0.93
S-Ar	** −4.4	−2.42
Ar-N	** −3.0	−2.09
S-Gn	−2.7	−1.60
Ar-Gn	−2.0	−1.22
Ba-Gn	−2.4	−1.07
Gol-Gol	0.2	0.22
Overjet	−0.1	−0.15
Overbite	−0.9	−1.29
Gol-Pg'	1.1	0.79
Ar-Gol	−1.6	−1.61
Pr Ba-Pg/OP	−1.8	−0.87
Pr Ar-Pg/OP	−2.4	−1.19

Included are the regression coefficient –rc– with accompanying test statistic –t– in the model where children with purely subjective symptoms at year 0 are compared to children with ADJ. The critical value at 31 degrees of freedom is t=2.04 for two–tailed testing. Cases where this value is exceeded are indicated with **.

8.4.2 Relationship between the component parts of the X–factor temporomandibular joint dysfunction and the growth variables Y at year 3

The same analyses were then carried out in the same way for the growth variables Y at year 3.
Only two regression coefficients were significant in the comparison of children with purely objective symptoms and children without temporomandibular joint dysfunction; they were Gol–Gol, +1.2 and overjet +0.8. Publication of the table was therefore deemed unnecessary.

No regression coefficients were significant for children with purely subjective symptoms compared to children without temporomandibular joint dysfunction. Publication of this table can also be dispensed with in this case.

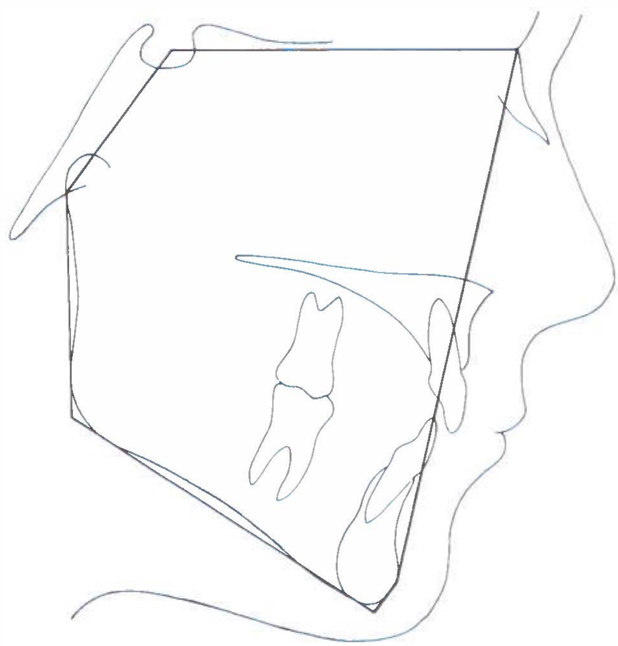
The results of the regression analyses of the growth variables Y at year 0 and year 3, in which children with ADJ are compared to children without temporomandibular joint dysfunction, are recorded in Table 8.6. The results at year 0 are also included in the table to make possible a quicker comparison.

Table 8.6 Regression coefficient and test statistic for the X–factor ADJ in models for the growth variables Y at year 0 and 3.

	year 0		year 3	
	rc	t	rc	t
Auricle	0.7	0.91	0.9	1.00
Mouth	−1.0	−0.76	−3.8	−2.40 **
∠ SN/OP	0.7	0.66	1.7	1.57
∠ SN/MP	2.7	1.88	3.3	2.19 **
∠ SN/RP	0.3	0.23	0.9	0.70
Gonial angle	2.3	1.39	2.2	1.34
∠ RP/OP	0.5	0.39	0.8	0.58
∠ S-N-Pg	** −2.2	−2.32	−2.5	−2.37 **
∠ S-N-A	−1.4	−1.34	−1.2	−0.96
∠ Ba-S-N	0.9	0.80	0.7	0.59
Y-axis	0.4	0.45	−1.1	−1.00
TFH	−0.9	−0.71	−1.0	−0.63
UFH	0.3	0.32	0.9	0.96
LFH	−1.4	−1.19	−1.8	−1.40
PFH	** −3.4	−2.87	−4.1	−3.44 **
S-N	0.1	0.20	0.2	0.29
S-Ar	−1.2	−1.69	−1.8	−2.50 **
Ar-N	−0.7	−0.74	−1.3	−1.36
S-Gn	** −3.1	−2.39	−3.6	−2.55 **
Ar-Gn	** −3.1	−2.53	−3.7	−2.59 **
Ba-Gn	−2.7	−1.92	−4.1	−2.62 **
Gol-Gol	0.6	1.32	1.1	2.07 **
Overjet	1.3	1.93	0.8	1.94
Overbite	0.0	0.09	−0.1	−0.23
Gol-Pg'	** −2.9	−2.72	−3.3	−2.86 **
Ar-Gol	−1.7	−1.70	−2.1	−2.00 **
Pr Ba-Pg/OP	** −2.9	−2.23	−3.6	−2.30 **
Pr Ar-Pg/OP	** −3.2	−2.54	−4.0	−2.61 **

Included are the regression coefficient –rc– with accompanying test statistic –t– in the model where children with ADJ are compared to the children without temporomandibular joint dysfunction. The critical value at 78 degrees of freedom is t=1.99 for two–tailed testing. Cases where this value is exceeded are indicated with **.

Figure 8.7 Tracing and reference polygon for children without temporomandibular joint dysfunction at year 3.



The absolute value of the regression coefficient at year 3 was consistently larger than at year 0. The deviant craniofacial pattern of children with ADJ is more pronounced after three years as a result. In the same three-year period, however, most of the skull dimensions have increased considerably. The thesis of an arrest in the growth of the mandible as supposed by Boering (1976[1], 1976[2]) is not supported here. Considering the increase in length which many of the growth variables Y display in the period studied, a lesser increase of about 0.5 mm can hardly be seen as a growth arrest. The growth of the mandible in these children will be more extensively examined in Chapter 10.

Finally, in order to be complete, the regression analyses of the growth variables Y at year 3 for children with purely subjective symptoms and children with purely objective symptoms are compared to children with ADJ. An X-factor has been drawn up for this purpose coded 0 for purely subjective symptoms and 1 for ADJ. The X-factor was coded analogously for the comparison of children with purely objective symptoms.

Figure 8.8 Superpositioning of the reference polygon at year 3, the polygon derived from it for ADJ, and the polygon derived from data from Riolo *et al. (Chapter 5).*

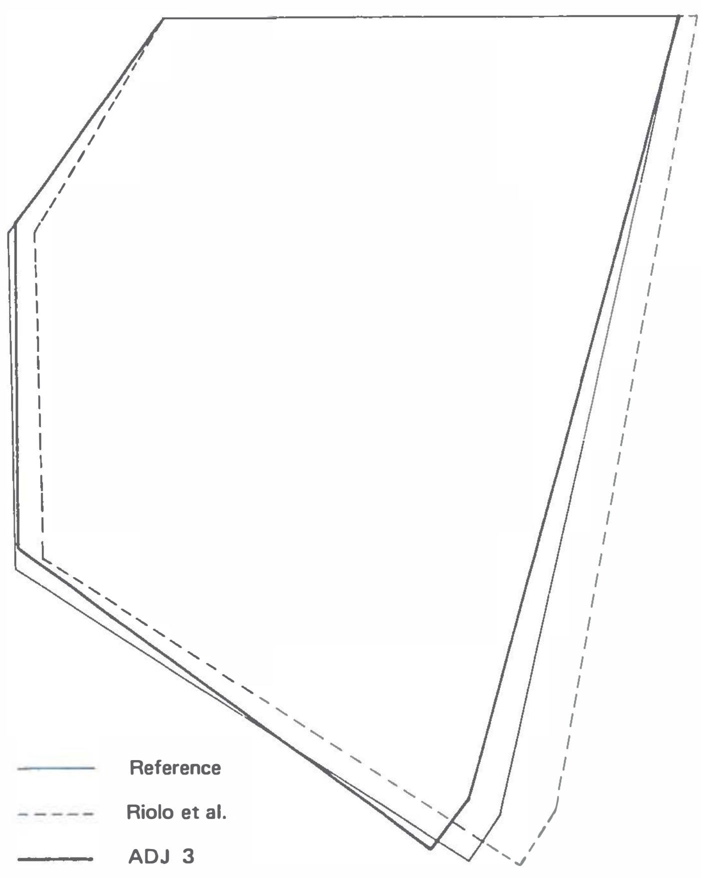


Table 8.7 Regression coefficient and test statistic of the X–factor which was coded 0 for purely subjective symptoms and 1 for ADJ, and for an X–factor which was coded 0 for purely objective symptoms and 1 for ADJ in models for the growth variables Y at year 3.

	Sub_0 x ADJ		Ob_0 x ADJ	
	rc	t	rc	t
Auricle	−1.4	−1.15	−0.3	−0.28
Mouth	−1.1	−0.48	−3.2	−1.33
∠ SN/OP	0.7	0.44	1.2	0.81
∠ SN/MP	2.3	1.12	1.9	0.95
∠ SN/RP	4.0	1.75	2.0	0.98
Gonial angle	−1.5	−0.58	−0.1	−0.03
∠ RP/OP	−3.3	−1.42	−0.8	−0.40
∠ S-N-Pg	−1.3	−0.92	−1.9	−1.45
∠ S-N-A	−2.5	−1.00	0.6	0.31
∠ Ba-S-N	0.8	0.45	−0.6	−0.44
Y-axis	−0.1	−0.07	0.7	0.49
TFH	−3.1	−1.62	−1.4	−0.66
UFH	−0.4	−0.31	−1.1	−0.87
LFH	−2.7	−1.51	−0.7	−0.41
PFH	** −5.2	−3.69	−3.4	−2.34 **
S-N	−0.6	−0.83	1.1	1.63
S-Ar	** −3.8	−3.37	−2.0	−2.19 **
Ar-N	** −4.3	−3.33	−1.7	−1.40
S-Gn	** −4.5	−2.56	−3.3	−1.74
Ar-Gn	−3.6	−1.98	−4.2	−2.12 **
Ba-Gn	−3.9	−1.72	−4.3	−1.82
Gol-Gol	0.5	0.43	0.1	0.14
Overjet	0.0	0.00	0.1	0.16
Overbite	−0.7	−1.08	0.0	0.05
Gol-Pg'	−1.1	−0.84	−2.6	−1.91
Ar-Gol	−2.4	−1.94	−2.2	−1.64
Pr Ba-Pg/OP	−3.6	−1.41	−3.2	−1.38
Pr Ar-Pg/OP	−4.1	−1.68	−3.7	−1.67

Included are the regression coefficient –rc– with accompanying test statistic –t– in the model where children with purely subjective symptoms and children with purely objective symptoms are compared to children with ADJ. The critical value at 31 degrees of freedom is t=2.04 for two–tailed testing. Cases where this value is exceeded are indicated with**.

Unlike year 0, when no regression coefficients were significant, at year 3 more regression coefficients were significant for children with purely objective symptoms compared to children with ADJ. This is not true of children with purely subjective symptoms, for whom one regression coefficient less was significant.

8.5 Discussion

Using Cohen's unweighted kappa (κ) (1968), we found insufficient agreement between the results of this study and data derived from the literature. For this reason new regression analyses were carried out; the X–factor temporomandibular joint dysfunction was replaced by different X–factors which correspond with its component parts. Because several qualifications had to be introduced in this connection, these factors were named "purely subjective symptoms", "purely objective symptoms", and "ADJ".
To begin with, the X–factors proved to explain the variance of the growth variables Y to different degrees. It then appeared that these X–factors were also unequivalent among themselves. The children without temporomandibular joint dysfunction were used as a reference group.
When no statements based on hard data about the results can be made because of the lack of a sufficient number of significant regression coefficients, some impression of the effect can still be obtained by weakening the strict agreement setting the significance level at $\alpha<0.05$ to a significance level, for example, of $\alpha<0.10$. Whenever this is done in this discussion it is always specifically stated.

Children with purely objective symptoms differ the least from the reference population. They also differ the least from children with ADJ, although a weakened significance level in this case does provide indications of differences. The pressing question arises as to whether "objective" really is objective and not something which results from subjective interpretation by the clinical investigators as being of importance.

Compared to children without temporomandibular joint dysfunction, for children with purely subjective symptoms it is primarily ∠SN/RP, and the smaller dimension for Gol–Pg', the corpus, which determine the differences (Figure 8.3).
Angle∠RP/OP (Chapter 5) is larger than in the reference population. Articulare is placed more inferiorly than Articulare in the reference childen. The position of Articulare compared to the children with ADJ is even more striking. The differences between children with purely subjective symptoms and the children with ADJ are illustrated in Figure 8.6.

The children with ADJ always form the most deviant group at year 0 (Figure 8.5). The problem seems less to be localized in Ar–Gol, the ramus, as described by Boering (1966, 1976[2]), than in Gol–Pg', the corpus. An explanation for this contradiction can be found in the anatomical structures which determine the point Articulare. An anterior position of Articulare, such as with ADJ, involves a superior displacement, which causes a greater part of the ramus to become visible on the cephalogram.

At year 3 the children with purely objective symptoms still display few differences compared to the reference population. The number of significant regression coefficients in comparison with children with ADJ is increased; that is, the difference between the group with purely objective symptoms and the group with ADJ increases. When the significance level is weakened for both analyses, the agreements with the reference population become steadily stronger because more regression coefficients with reference to children with ADJ are significant, and there are still few regression coefficients significant with respect to the reference group.

The children with purely subjective symptoms exhibit hardly any differences from the reference population at year 3. This means that a considerable gap has been closed since year 0. Whether this is the result of orthodontic treatment and/or growth has not been investigated further. The determination of whether or not treatment had any influence in this respect was likewise considered beyond the scope of this investigation. The different positions of Articulare are still present for the children with ADJ as illustrated in Figure 8.6.

At year 3 the condition of the children with ADJ is even more pronounced. A conclusion cannot immediately be drawn that a mouth opening which is 4 mm smaller than that of the reference children is due to a disease process in the joint. This smaller dimension can, in part, result from other dimensions which are too small, such as Ar–Gol and Gol–Pg'. However, the finding from Chapter 6 that the mobility with ADJ, as determined from the Parma radiograph, was enlarged less often, leads one to believe that the origin of restricted mouth opening must, after all, be sought in the joint. In Figure 8.8 can be seen the difference between the reference group children and those with ADJ at year 3.

To conclude, it has been ascertained that by using regression analysis the influence can be demonstrated of temporomandibular joint dysfunction, as defined in various ways, on craniofacial pattern and dimensions. The regression analysis proved itself able to explain these craniofacial patterns satisfactorily, even when a relatively simple model was used. The analyses yield estimates of the influence of the factors being considered in this model; these estimates are always independent of the relationship with the other factors.

Chapter 9

Factor analysis

9.1 Introduction

In this chapter is discussed how understanding of the structure of the set of growth variables Y can be further increased by using factor analysis. The most important property of factor analysis is its capacity to reduce the amount of data used to characterize the individuals to more manageable proportions, with a relatively limited loss of substantial information. All the measurements of the cephalograms and photos can thus be summarized into a limited number of factors. These factors are determined by clusters of related variables. Following the example of the social sciences, for instance, where a similar procedure is used, a designation has been sought for these factors which describes their content. Factor analysis has in the past been used only to a very limited extent in the field of craniofacial growth. There is therefore very little literature to be found on this topic (Solow 1966, 1967, 1970).

Three essential steps can be distinguished in carrying out the analysis (Harman 1967; Brand-Koolen 1972; SPSS 1974):

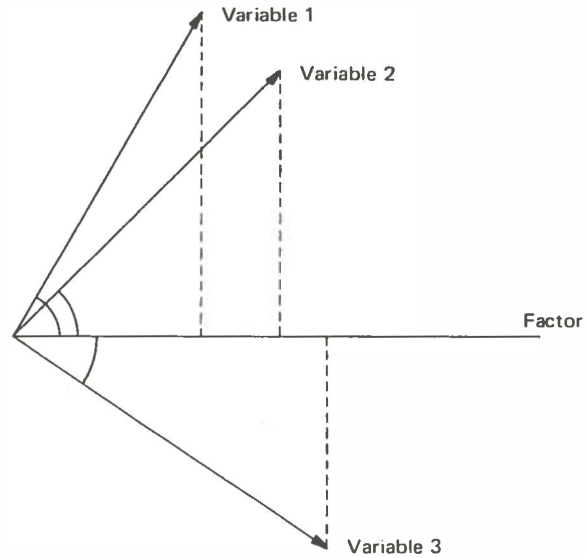
a. A correlation matrix is prepared (CORRELATE).
b. The initial factors are extracted (FACTOR).
c. The factors are rotated to a terminal solution in a search for simpler and more interpretable factors (ROTATE).

A set of relevant variables is the first necessity for setting up the correlation matrix. Of course, for this study a choice was made from the growth variables Y defined in Chapter 3.

Table 9.1 Factors from Figure 9.2 before and after rotation.

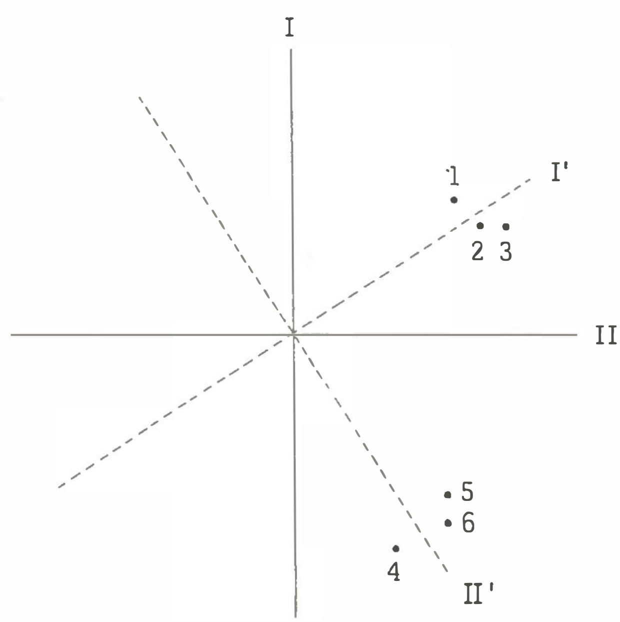
variables	before rotation I	before rotation II	after rotation I'	after rotation II'
1	+	+	+ +	
2	+	+	+ +	
3	+	+ +	+ +	
4	– –	+		– –
5	–	+		– –
6	–	+		– –

Figure 9.1 Loading on a factor.
The loading of a variable on a factor is equal to the cosine of the angle which this variable makes with the factor, when the variable is standardized at a length of 1.



	Factor loading	
variable 1	500	(cos 60°)
2	700	(cos 45°)
3	900	(cos 30°)

Figure 9.2 Six variables on a two dimensional factor space.



Ten initial factors were next extracted from this correlation matrix by means of exact mathematical transformations of the original data, called a principal-component analysis. The factors are extracted in such a way that one factor is independent of the other; that is, the factors are orthogonal.

Finally, an orthogonal rotation is carried out,based on the assumed independence of the initial factors. In an orthogonal rotation the axes are located perpendicular to each other. A rotation according to the Varimax criterion was used, which centers on simplifying the columns of a factor matrix. This is done by making high loadings higher and low loadings lower, or expressed differently, by maximizing the variance of the squared loadings in each column.

A considered choice has been made in this study of the number of factors to be rotated. In factor analysis, the decision of how many factors to rotate is based on a compromise between reduction, involving a loss of information, and the achievement of a simpler and theoretically more meaningful factor structure. This choice of factors is determined by the investigator, not by the method (Brand-Koolen 1972). In a terminal solution of only two rotated factors can be clearly seen that a considerable reduction has taken place. However, a number of variables will have low loadings on these factors so that they have no role in the factor structure. If too many factors are rotated, twenty-five, for example (assuming that there are enough initial factors with an eigenvalue >0), then the variables are divided among all these factors, and a diffuse and difficult to interpret situation is created. Additionally, in such a situation the existence of a factor will be determined largely by the total number of growth variables Y involved in the analysis. The addition of one variable therefore causes a shifting within the factors. As a point of orientation for making a considered choice of factors, the factor matrices were determined and interpreted for two, three, four and five rotated factors. Rotation of four factors proved to be the most interpretable.

Before the results can be described, a number of assumptions must be defined (9.2).
The results of the factor analysis are presented in two parts. The complete matrices of four rotated factors from the groups are successively presented in the first part (9.3). In the second part (9.4) a comparison is made of the component groups per factor. The chapter is concluded with a brief discussion (9.5).

9.2 Preliminary conditions

In Chapters 5 and 8 it was shown that temporomandibular joint dysfunction is responsible for a deviant craniofacial pattern, measured sagittally on the lateral cephalogram. In Chapter 6 it was seen that this effect could not be demonstrated transversally, or differentially for the left or the right side. The influence of temporomandibular joint dysfunction on the transversal development of the skull was not investigated. Two simplifications can now be introduced into the search for relationships among the growth variables Y themselves. First, in all the measurements where left and right is separately reported, the two measurements can be averaged. Secondly, the analysis can be confined to the growth variables Y from the lateral cephalogram, because the frontal cephalogram and the photographs are not expected to be important sources of information in this particular analysis.

Because a pattern was sought within the growth variables Y from the lateral cephalogram, the reduction of the number of these variables as carried out with the regression analyses in Chapters 5 and 8 could not be employed.
Age, sex, appliance (i.e. type of orthodontic treatment), and the difference between ∠S-N-A minus ∠S-N-Pg, or ∠A-N-Pg, were added to the factor analysis. The first three variables were included because the regression analysis had demonstrated that they were strongly related to a number of growth variables Y. Angle ∠A-N-Pg was added because it expresses the differential between maxilla and mandible, and can therefore possibly provide prognoses of how upper and lower jaw relate to each other. Angle ∠A-N-B, which is often used in orthodontic studies, was not employed in the computations because point B is too strongly influenced by the position of the lower dental arch in relation to the mandible.
These added variables could be the cause of the formation of clusters which, if these variables were absent from the analysis, could then be incorrectly interpreted. A final selection of thirty-six growth variables Y was made from the total set and entered into the factor analysis.

The factor analysis is limited to the situation at year 0. The children therefore had not yet been treated. The ages in the group at year 0 varied from eight years and six months to sixteen years and three months, so that it was possible to gain an insight into the effect of age.

Table 9.2 Factor loadings for 36 variables; 4 factors are orthogonally rotated according to the Varimax criterion.

The factor loadings for the group of children without temporomandibular joint dysfunction are given as an example. The sometimes very high loadings such as for the variables 30 and 32 in factor 1 are striking.

****
*** ROTATE ***
****

THE FIRST 4 FACTORS ARE ROTATED ACCORDING TO

THE VARIMAX-CRITERION

RESULTING ROTATED FACTORS

	1	2	3	4
1	-201	682	52	3
2	134	744	-1	33
3	-240	575	-591	373
4	-155	403	-446	671
5	-206	458	278	524
6	-36	61	-610	373
7	-65	184	-874	-90
8	399	-648	268	-435
9	-426	132	-537	307
10	50	-609	-203	-203
11	116	831	-86	-112
12	-386	29	-46	846
13	637	52	92	749
14	519	473	329	243
15	496	-280	-117	713
16	603	-429	393	36
17	770	-27	12	61
18	397	-459	243	147
19	766	-17	103	91
20	835	-312	216	328
21	934	-172	214	75
22	938	-156	207	62
23	930	-42	207	-63
24	935	-27	203	-73
25	-16	38	239	-67
26	45	107	561	1
27	-40	-10	292	-429
28	806	-187	356	41
29	653	-128	352	-183
30	952	53	-35	-211
31	917	-95	-166	-141
32	948	80	-50	-208
33	914	-65	-181	-137
34	563	229	459	320
35	-314	306	114	-122
36	374	85	511	141

SUM OF LOADINGS

13546	1857	1758	3667

SUM OF SQUARED LOADINGS

12619	4353	4005	3844

The effect that orthodontic treatment might have on the pattern of the growth variables Y, and vice versa, is beyond the scope of this investigation.

A choice was then made of which factor matrices were to be compared, and in relation to which reference groups. One possibility was to compare the factor matrices of the group of children without temporomandibular joint dysfunction to the group with dysfunction, according to the original criteria established in this study. In Chapter 8, however, it was shown that the children with temporomandibular joint dysfunction did not form a homogeneous group; it therefore seemed obvious that a factor analysis of the component parts of that dysfunction should be carried out. Another possibility was to divide the group of children with an Angle class II, division 1 malocclusion into two groups according to the type of orthodontic treatment. This possibility was not explored in this study.

The same technical refinement as that described in Chapter 8 was used for the analysis here in order to demarcate the seperate components. The influence of ADJ on the subjective and objective symptoms is also eliminated here. Procedures analogous to those used in that chapter are employed here so that purely subjective and purely objective symptoms are now referred to.

Using factor analysis, a deeper understanding of the structure of the growth variables Y was then sought for the children with purely subjective symptoms at year 0, with purely objective symptoms at year 0, and with ADJ. The reference is the group of children without temporomandibular joint dysfunction.
Finally, to make the tables readable, surveyable and interpretable, the following notation is used: a factor loading from 0.7 to 1.0 is called very high and is indicated with ++ or ––; a factor loading from about 0.5 to 0.7 is high and is indicated with + or – (Brand–Koolen 1972). Because a different value must be assigned to the variables Age, Sex and Appliance than to the variables connected with the craniofacial pattern, the height of the factor loading itself is always given for these three variables. The minus sign indicates a negative factor loading. The sign of the loadings within one factor is unimportant and may be exchanged for all the loadings on the factor at the same time. An example of a print–out of all the loadings in a factor matrix is shown in Table 9.2.

9.3 The factor matrices

9.3.1 The factor matrix for the reference group

The results of the factor analysis for sixty–one children without temporomandibular joint dysfunction are shown in Table 9.3. The boy–girl ratio was about the same as in the total group involved in the investigation. The percentage of variance explained was sixty–nine.

Table 9.3 Factor analysis of 36 variables, in which 4 factors are orthogonally rotated according to the Varimax criterion.

	1	2	3	4
∠ SN/FH		+		
∠ SN/PP		++		
∠ SN/OP		+	–	
∠ SN/MP				+
∠ SN/RP				+
Gonial angle			–	
∠ RP/OP			––	
∠ S-N-Pg		–		
∠ A-N-Pg			–	
∠ S-N-A		–		
∠ Ba-S-N		++		
Y-axis				++
TFH	+			++
UFH	+			
LFH	+			++
PFH	+			
S-N	++			
S-Ar				
Ar-N	++			
S-Gn	++			
Ar-Gn	++			
Ar-Pg	++			
Ba-Gn	++			
Ba-Pg	++			
Gol-Gol				
Overjet			+	
Overbite				
Gol-Pg'	++			
Ar-Gol	+			
Pr Ba-Pg/OP	++			
Pr Ar-Pg/OP	++			
Pr Ba-Gn/OP	++			
Pr Ar-Gn/OP	++			
AGE	563	229	459	320
SEX	–314	306	114	–122
Appliance	374	85	511	141

The factor loadings at year 0 for the group of children without temporomandibular joint dysfunction are schematically presented; ++ or –– corresponds with a loading of 0.7–1.0 while + or – corresponds with a loading of about 0.5–0.7. This group consisted of 61 children. The mean age was 12 years and 2 months. The percentage of variance explained was 69.

A cluster can be seen in factor 1 composed solely of linear measurements within the skull. The only linear dimension which is absent is S–Ar, whose size is thus not related with the other linear measurements. Further, the vertical dimensions TFH, UFH, LFH, PFH and Ar–Gol, the ramus, were somewhat less strongly related to the factor; the same was true of age. It was to be expected that age was related to the factor; the size of these linear dimensions in children are determined largely by age, though in conjunction with other influences. The loading for Age can be compared with the effect of an electrical rectifier; there is only one direction of transmission. Thus small dimensions belong to younger ages, and large dimensions to older ages. The direction of the effect is thus determined, so that it is now definitely established that the variables are arranged according to size in time.
The fact that the loading for the variable age in this factor was not very high shows that this size is not dependent on the age alone. It is interesting to note that there is no clear relationship between these dimensions and sex –the skull dimensions of girls are, after all, smaller than those of boys. Because factor 1 only comprises variables which determine the size of the craniofacial skeleton, it received the name SIZE.

A cluster of angular measurements has been isolated in factor 2. It was to be expected that these angular measurements would form one cluster because they determine the shape of the head. The angles ∠SN/MP, ∠SN/RP, the gonial angle, ∠RP/OP, ∠A–N–Pg and the Y–axis did not receive a high loading. Because of the striking relationship of this factor with the shape of the craniofacial skeleton and consequently with the profile, it received the name SHAPE.

The cluster of high loading variables in factor 3 is composed of angular dimensions from the mandible, among others, but with ∠SN/MP and ∠SN/RP excluded. The affinity with the overjet is striking–so much so that the overjet is smaller with a larger gonial angle, a larger ∠SN/OP, ∠RP/OP and ∠A–N–Pg. The high loadings for the variables in this factor are all an expression of the shape and position of the mandible relative to the skull.
The presence of high loadings for the combination age (459) and appliance (511) in this factor is interesting. The combination seems logical enough, since a high score for age –the older children– would lead one to expect a high score for appliance (Begg). The reverse is equally likely –the combination of young children and activator. It must be concluded from the loading for age in this factor that there is a tendency in the older children for ∠A–N–Pg to be small and the overjet to be large. Because factor 3 comprises variables which are an expression of the shape and position of the mandible, it has been called MANDIBLE.

The cluster in factor 4 is formed by high loadings for the measurements of the vertical dimensions with the exception of the UFH and PFH. Because the Y–axis almost forms a diagonal through the craniofacial skeleton, the angular measurement is influenced both by the vertical and by the horizontal position of Gnathion. This factor received the name FACIAL HEIGHT.

S–Ar, Gol–Gol, the overbite and sex showed no high loadings on any of the factors.

Summary: factor 1 SIZE
factor 2 SHAPE
factor 3 MANDIBLE
factor 4 FACIAL HEIGHT

9.3.2. The factor matrix for the group of children with purely subjective symptoms

The results of the factor analysis for the fourteen children with purely subjective symptoms are shown in Table 9.4. The boy–girl ratio was about the same as in the total group investigated. The percentage of variance explained was seventy–two.

There are many points of agreement between the factor matrix of the children with purely subjective symptoms and the factor matrix of the children without temporomandibular joint dysfunction, but definite differences are also visible. These differences will be discussed for each factor.

SIZE
There is a lower loading in this factor for most of the vertical dimensions, for S–N, Ar–N, and for the computed projections proceeding from Articulare on the Occlusal Plane, compared to the factor matrix of the reference group. A higher loading is noted for ∠SN/OP. The strength of the relationship with the factor varied alternately between Ar–Gol and Gol–Pg'. The lower loading for Ar–Gol, the ramus, is explored further in Chapter 10 and with Figure 10.8; it is apparently a result of the anatomical relationships of the craniofacial structures which determine Articulare. The nomenclature SIZE, however, still seems apt. Since Age has a high loading on this factor, the size of the variables can be ranked in time. Angle ∠SN/OP is more acute for older children, which means that the Occlusal Plane is inclined toward S–N; the linear dimensions from Sella, Basion and Articulare to the chin are all also larger than in the younger children. This is also true for the linear dimensions of the mandible; Ar–Gol, the ramus, seems more closely related to the factor than Gol–Pg', the corpus. The greater lengths of the projections from the Basion to the chin for older children indicate that the chin and the maxilla move in a comparable direction.

Table 9.4 Factor analysis of 36 variables, in which 4 factors are orthogonally rotated according to the Varimax criterion.

	1	2	3	4
∠ SN/FH		+ +		
∠ SN/PP		+ +		
∠ SN/OP	–			+
∠ SN/MP		+	–	
∠ SN/RP		+ +		
Gonial angle			– –	
∠ RP/OP		– –		
∠ S-N-Pg		– –		
∠ A-N-Pg				+
∠ S-N-A		– –		
∠ Ba-S-N				
Y-axis				+ +
TFH			–	+
UFH		+ +		
LFH				+
PFH	+	– –		
S-N				
S-Ar		–		
Ar-N	+			
S-Gn	+ +			
Ar-Gn	+ +		–	
Ar-Pg	+ +		–	
Ba-Gn	+ +			
Ba-Pg	+ +			
Gol-Gol			–	
Overjet		+		
Overbite			+ +	
Gol-Pg'	+			
Ar-Gol	+ +			
Pr Ba-Pg/OP	+ +			
Pr Ar-Pg/OP	+	–		
Pr Ba-Gn/OP	+ +			
Pr Ar-Gn/OP	+	–		
AGE	500	235	−241	−153
SEX	−25	−126	−648	−532
Appliance	19	72	−64	−354

The factor loadings at year 0 for the group of children with purely subjective symptoms are schematically presented; qq or - - corresponds with a loading of 0.7–1.0, while + or – corresponds with a loading of about 0.5–0.7. This group consisted of 14 children. The mean age was 13 years and 11 months. The percentage of variance explained was 72.

SHAPE

No high loadings were noted for ∠SN/OP and ∠Ba–S–N in this factor. A higher loading was noted for ∠SN/FH, ∠SN/MP, ∠SN/RP, ∠RP/OP, ∠S–N–Pg, ∠S–N–A, UFH, PFH, S–Ar, overjet and the projections from Articulare on the Occlusal Plane. Still, SHAPE seems to have been properly named.

The factor describes relationships between angular measurements. Results, among others, of large values for ∠SN / FH and ∠SN / PP are a receded point A and chin, a large UFH but a small PFH, a more highly placed Articulare (S–Ar) and a larger overjet. The reverse, of course, is also true.

The data derived from this factor do not seem to contain any contradictions. It is unclear exactly why particular values for the variables are large or small. In any case, the causes need not be sought in a possible connection with age and sex, since both received virtually no loading on this factor.

MANDIBLE

With the exception of the gonial angle, an entirely new factor has arisen here. The loading for Age (241) is also low, so that the size of the variables in this factor, unlike the reference group matrix, cannot be ranked in time without reservation. This certainly does not make the interpretation of the data any simpler. Perhaps the variable sex can give us something more to go by. It is interesting that sex is highly loaded on this factor, but not in the reference matrix. The variance explained by Age is evidently subordinate to the relationship of sex with this factor. The boys display a smaller ∠SN/MP, gonial angle, TFH, smaller diagonals Ar–Pg and Ar–Gn, and smaller projections on the Occlusal Plane. The opposite is true for the girls. The data are not internally contradictory, though the relationship with sex is the opposite of what would be expected from the regression analyses.

FACIAL HEIGHT

The factor FACIAL HEIGHT is in reasonable agreement with its matching reference group factor. The nomenclature FACIAL HEIGHT also seems justified in this case.

Most of the variables which had a high loading for the reference factor also had one here. A higher loading was noted for ∠SN / OP and ∠A–N–Pg; no high loading was noted for ∠SN / MP or ∠SN / RP. When TFH is large a number of measurements vary with it and are also large: namely ∠SN / OP, ∠A–N–Pg, Y–axis, and LFH; this is more true for boys than for girls.

Angle ∠Ba–S–N, S–N and Appliance did not load high on any factor.

9.3.3 The factor matrix of the group of children with purely objective symptoms

The results of the factor analysis for the seventeen children with purely objective symptoms are presented in Table 9.5. The boy–girl ratio was about the same as in the total group of children studied. The percentage of variance explained was seventy-six.

This factor matrix contains many, high loadings compared to the matrix of the reference group. The factors will be discussed consecutively.

SIZE

This factor displayed a large degree of agreement with

Table 9.5 Factor analysis of 36 variables, in which 4 factors are orthogonally rotated according to the Varimax criterion.

	1	2	3	4
∠ SN/FH		+		
∠ SN/PP		+ +		
∠ SN/OP		+ +		
∠ SN/MP	–			
∠ SN/RP		+	+	
Gonial angle			– –	
∠ RP/OP			– –	
∠ S-N-Pg	+	– –		
∠ A-N-Pg	–			
∠ S-N-A		– –		
∠ Ba-S-N				
Y-axis		+		+
TFH	+ +			+
UFH	+ +	+		
LFH				+ +
PFH	+ +	–		
S-N	+ +			
S-Ar				
Ar-N	+ +			
S-Gn	+ +			
Ar-Gn	+ +			
Ar-Pg	+ +			
Ba-Gn	+ +			
Ba-Pg	+ +			
Gol-Gol				
Overjet				–
Overbite				– –
Gol-Pg′	+ +			
Ar-Gol	+ +			
Pr Ba-Pg/OP	+ +			
Pr Ar-Pg/OP	+ +			
Pr Ba-Gn/OP	+ +			
Pr Ar-Gn/OP	+ +			
AGE	719	43	–295	–116
SEX	–367	–365	310	71
Appliance	672	157	77	457

The factor loadings at year 0 for the group of children with purely objective symptoms are schematically presented; ++ or - - corresponds with a loading of 0.7–1.0, while + or – corresponds with a loading of about 0.5–0.7. This group consisted of 17 children. The mean age was 12 years and 2 months. The percentage of variance explained was 76.

the reference factor matrix with LFH as the only high loading variable which was absent. A higher loading was noted for ∠SN/MP, ∠S–N–Pg, ∠A–N–Pg, TFH, UFH, PFH, Ar–Gol, Age and Appliance. SIZE also seems here to have been correctly named.
Because of the high loading for Age, a dynamic interpretation is also permissible here. The ∠SN/MP is smaller for older children than for younger ones. The high loading for PFH can perhaps help to explain why the anterior face height is not shortened as a result of this smaller ∠SN/MP –the opposite is actually true. The presence of ∠S–N–Pg with a high loading in this factor is most striking; this angle does not have a high loading in the reference factor matrix. Angle ∠S–N–Pg is larger for older children than for younger children. At the same time, ∠A–N–Pg is smaller, but the overjet, strangely enough, does not have a high loading. The loadings do not contradict one another.

SHAPE
A high loading is lacking for ∠Ba–S–N. A higher loading was noted for ∠SN/OP, ∠SN/RP, ∠S–N–Pg, ∠S–N–A, Y–axis, UFH and PFH. The loadings do not contradict one another. The name SHAPE also seems justified here.

MANDIBLE
There are no high loadings in this factor for ∠SN/OP, ∠A–N–Pg, overjet, Age or Appliance. A higher loading was noted for ∠SN/RP and gonial angle. It appears that this factor is determined by ∠SN/RP, to which the gonial angle adjusts. The three loadings do not contradict one another.

FACIAL HEIGHT
In this factor high loadings were lacking for ∠SN/MP and ∠SN/RP. On the other hand, there were high loadings for overjet and overbite. The name FACIAL HEIGHT also seems correct here.
A large dimension for LFH is accompanied by a large TFH, a large Y–axis and small overbite. How a small overjet can be related to the immediately previous findings is unclear.

No high loadings were noted for ∠Ba–S–N, S–Ar, Gol–Gol and Sex in any factor.

9.3.4 The factor matrix for the group of children with ADJ

The results of the factor analysis for the twenty–five children with ADJ are reported in Table 9.6. The boy–girl ratio was about the same as in the total group studied. The percentage of the variance explained was sixty–five.

This factor matrix displays many points of agreement with the reference matrix, but there are also many differences. These will be discussed here factor by factor.

SIZE
High loadings were not noted for the vertical dimensions S–N and Ar–N. A higher loading was noted for ∠SN/MP, ∠S–N–Pg and Y-axis. All the variables with a high loading are related to the chin. The name SIZE also seems justified here.
The loading for Age (450) makes it probable that some connection with the factor does exist. An interesting phenomenon is that ∠S–N–Pg is large when linear

Table 9.6 Factor analysis of 36 variables, in which 4 factors are orthogonally rotated according to the Varimax criterion.

	1	2	3	4
∠ SN/FH				– –
∠ SN/PP				
∠ SN/OP			–	
∠ SN/MP	–			+
∠ SN/RP			+ +	
Gonial angle			– –	
∠ RP/OP			– –	
∠ S-N-Pg	+ +			
∠ A-N-Pg				
∠ S-N-A				
∠ Ba-S-N				–
Y-axis	– –			+
TFH				+ +
UFH				
LFH				+
PFH				
S-N		+		
S-Ar		+ +		
Ar-N		+ +		
S-Gn	+ +			+
Ar-Gn	+ +			
Ar-Pg	+ +			
Ba-Gn	+ +			
Ba-Pg	+ +			
Gol-Gol				
Overjet				
Overbite		+		
Gol-Pg′	+ +		+	
Ar-Gol	+			
Pr Ba-Pg/OP	+ +			
Pr Ar-Pg/OP	+ +			
Pr Ba-Gn/OP	+ +			
Pr Ar-Gn/OP	+ +			
AGE	450	43	553	208
SEX	–107	–584	8	189
Appliance	261	–100	421	129

The factor loadings at year 0 of the group of children with ADJ are schematically presented; ++ or -- corresponds with a loading of 0.7–1.0 while + or – corresponds with a loading of about 0.5–0.7. This group consisted of 25 children. The mean age was 13 years and 4 months. The percentage of variance explained was 65.

dimensions such as S–Gn, Ba–Gn or Ar–Gn are large, and it is small when these dimensions are small. This relationship is stronger than in the other matrices, but it does not contradict the other loadings.

SHAPE
Factor 2 has little in common with the SHAPE of the reference factor matrix, but seems rather to be partially determined by sex. Boys have a large dimension for S–N combined with a large dimension for S–Ar, Ar–N (Articulare in an inferoposterior position) and a large overbite. For girls the situation is reversed.

MANDIBLE
Angle ∠A–N–Pg, overjet and appliance did not receive a high loading. A higher loading was noted for ∠SN/RP, gonial angle, and Gol–Pg', (the corpus). The presence of a high loading for Age permits of a dynamic interpretation. The loading for Appliance is diminished. The name MANDIBLE seems correctly chosen.
The Occlusal Plane in older children is inclined toward S–N; unlike ∠SN/RP, the gonial angle and ∠RP/OP are less obtuse, and Gol–Pg' (the corpus) is greater than for younger children.

FACIAL HEIGHT
The factor FACIAL HEIGHT is similar to the same factor in the reference factor matrix.
Angle ∠SN/RP did not receive a high loading; ∠SN/FH, ∠Ba–S–N, Y-axis, and S–Gn received a high loading. The high loading for S–Gn is striking.

No high loadings were scored on any factor for ∠SN/PP, ∠A–N–Pg, ∠S–N–A, UFH, PFH, Gol–Gol, overjet or appliance.

9.4 Comparisons among the groups factor by factor

The Tables 9.7 to and including 9.10 have been constructed to promote ease of comparison of the different factor matrices. In each table the high and very high loadings from the different analyses are noted and sorted per factor. The notation is the same as in the rest of the tables.

9.4.1 SIZE

The sagittal linear dimensions and the projections from Ba–Pg and Ba–Gn on the Occlusal Plane have a very high loading in all the groups. Because of a high loading for Age in the reference matrix, the size of the variables seems to agree with what might be expected as a result of growth. The identical loadings for TFH, UFH, LFH, PFH and Ar–Gol, the ramus, can be an indication of a gradual vertical development.

The factor matrix of children with purely subjective symptoms exhibits no high loadings for the vertical dimensions TFH, UFH and LFH. Because OP, the Occlusal Plane, is inclined more toward S–N in older children than in younger children, the chance increases that an enlargement of the mandible will benefit the profile. The very high loading for Ar–Gol, the ramus, is perhaps an indication that this increase in length does,

Table 9.7 Comparison of the loadings from the different analyses for the factor SIZE.

	R	S	O	ADJ
∠ SN/FH				
∠ SN/PP				
∠ SN/OP		–		
∠ SN/MP			–	–
∠ SN/RP				
Gonial angle				
∠ RP/OP				
∠ S-N-Pg			+	+ +
∠ A-N-Pg			–	
∠ S-N-A				
∠ Ba-S-N				
Y-axis				– –
TFH	+		+ +	
UFH	+		+ +	
LFH	+			
PFH	+	+	+ +	
S-N	+ +		+ +	
S-Ar				
Ar-N	+ +	+	+ +	
S-Gn	+ +	+ +	+ +	+ +
Ar-Gn	+ +	+ +	+ +	+ +
Ar-Pg	+ +	+ +	+ +	+ +
Ba-Gn	+ +	+ +	+ +	+ +
Ba-Pg	+ +	+ +	+ +	+ +
Gol-Gol				
Overjet				
Overbite				
Gol-Pg'	+ +	+	+ +	+ +
Ar-Gol	+	+ +	+ +	+
Pr Ba-Pg/OP	+ +	+ +	+ +	+ +
Pr Ar-Pg/OP	+ +	+	+ +	+ +
Pr Ba-Gn/OP	+ +	+ +	+ +	+ +
Pr Ar-Gn/OP	+ +	+	+ +	+ +
AGE	563	500	719	450
SEX	−314	−25	−367	−107
Appliance	374	19	672	261

In the table are presented the factor loadings at year 0 for the children without temporomandibular joint dysfunction, the children with purely subjective symptoms, with purely objective symptoms, and with ADJ; ++ or -- corresponds with a factor loading of 0.7–1.0, + or – corresponds with a factor loading of about 0.5–0.7.

in fact, take place. The loadings for the projections on the Occlusal Plane are less strongly related to the factor than in the other groups.

It is striking that the children with purely objective symptoms have many very high loadings, including one for Age. The relationship to the vertical dimensions is even stronger than in the reference factor matrix. The high loading for ∠SN/MP on this factor apparently precludes a high loading for LFH. The notation of a high loading for ∠S–N–Pg and opposite to ∠A–N–Pg is surprising; the only explanation would seem to be that the chin lies more anteriorly in older children. The high loading for appliance does not, unfortunately, explain why the older children whose chin lies more forward, still were treated with Begg. Perhaps an answer can be found in an analysis of the dental casts. These were not employed in this study.

There is a rather high loading for Age for the children with ADJ. All the high loadings have something to do with variables related to the position of the chin. A high loading for the vertical dimensions accompanied by a negative relationship with the Y–axis and ∠SN/MP was not to be expected, and neither did it make an appearance. It is not immediately clear what –except for Age– led to cluster forming within this factor, although we can be positive that the dimensions reflected in the variables increase over time. It is related in any case to the very high loadings for ∠S–N–Pg and Y–axis, since the rest of the factor strongly resembles the reference factor matrix.

9.4.2 SHAPE

Except for the children with ADJ, for whom this factor seems to have a totally different meaning, there is usually strong agreement among the matrices. There is a strong relationship with the profile. Yet it is still not known why these high loadings occur. This is explored further in Chapter 10.

In the children with purely subjective symptoms, a strongly convex profile –large ∠SN/FH, ∠SN/MP and small ∠S–N–Pg– has far-reaching consequences. The anterior part of the maxilla (UFH) is retro inclined (∠S–N–A, ∠SN/PP); Gonion and Articulare lie more superiorly and there is a large overjet. The projections of the diagonals through the jaw on the Occlusal Plane are therefore small.

The factor for children with purely objective symptoms is an intermediate form between the one described for children with purely subjective symptoms and the reference factor matrix.

For the children with ADJ the factor is highly dependent on the position of Articulare (S–Ar and Ar–N). The negative relation with sex is unexpected, but apparently partially determines this position.

Table 9.8 Comparison of the loadings from the different analyses for the factor SHAPE.

	R	S	O	ADJ
∠ SN/FH	+	+ +	+	
∠ SN/PP	+ +	+ +	+ +	
∠ SN/OP	+		+ +	
∠ SN/MP		+		
∠ SN/RP		+ +	+	
Gonial angle				
∠ RP/OP		− −		
∠ S-N-Pg	−	− −	− −	
∠ A-N-Pg				
∠ S-N-A	−	− −	− −	
∠ Ba-S-N	+ +			
Y-axis			+	
TFH				
UFH		+ +	+	
LFH				
PFH		− −	−	
S-N				+
S-Ar		−		+ +
Ar-N				+ +
S-Gn				
Ar-Gn				
Ar-Pg				
Ba-Gn				
Ba-Pg				
Gol-Gol				
Overjet		+		
Overbite				+
Gol-Pg′				
Ar-Gol				
Pr Ba-Pg/OP				
Pr Ar-Pg/OP		−		
Pr Ba-Gn/OP				
Pr Ar-Gn/OP		−		
AGE	229	235	43	43
SEX	306	−126	−365	−584
Appliance	85	72	157	−100

In the table are presented the factor loadings at year 0 for the children without temporomandibular joint dysfunction, the children with purely subjective symptoms, with purely objective symptoms, and with ADJ; ++ or −− corresponds with a factor loading of 0.7–1.0, + or − corresponds with a factor loading of about 0.5–0.7.

9.4.3 MANDIBLE

The only high loading variable in all four matrices is gonial angle; for three out of four ∠RP/OP was highly loaded. This angle is described in Chapter 5 as a possible measure of that part of the linear increase of Ar–Gol, the ramus, which can bring about displacement of the mandible in its relationship with the maxilla. It appears from the reference factor matrix that as the child becomes older, there is a diminishing chance that there will be a good compensation in the occlusion.

Table 9.9 Comparison of the loadings from the different analyses for the factor MANDIBLE.

	R	S	O	ADJ
∠ SN/FH				
∠ SN/PP				
∠ SN/OP	−			−
∠ SN/MP		−		
∠ SN/RP			+	+ +
Gonial angle	−	− −	− −	− −
∠ RP/OP	− −		− −	− −
∠ S-N-Pg				
∠ A-N-Pg	−			
∠ S-N-A				
∠ Ba-S-N				
Y-axis				
TFH		−		
UFH				
LFH				
PFH				
S-N				
S-Ar				
Ar-N				
S-Gn				
Ar-Gn		−		
Ar-Pg		−		
Ba-Gn				
Ba-Pg				
Gol-Gol		−		
Overjet	+			
Overbite		+ +		
Gol-Pg′				+
Ar-Gol				
Pr Ba-Pg/OP				
Pr Ar-Pg/OP				
Pr Ba-Gn/OP				
Pr Ar-Gn/OP				
AGE	459	−241	−295	553
SEX	114	−648	310	8
Appliance	511	−64	77	421

In the table are presented the factor loadings at year 0 for the children without temporomandibular joint dysfunction, the children with purely subjective symptoms, with purely objective symptoms, and with ADJ; ++ or −− corresponds with a factor loading of 0.7–1.0, + or − corresponds with a factor loading of about 0.5–0.7.

There was no high loading for Age for the children with purely subjective symptoms, but there was a high loading for sex. It appears that there is an affinity with the reference factor matrix via the gonial angle, but that the cause of the formation of a cluster of variables with high loadings is entirely different than in the other factor matrices.

For children with purely objective symptoms, the factor is also bound up with the gonial angle. When ∠SN/RP is large, the gonial angle and ∠RP/OP are small.

The factor has a still stronger relationship with ∠SN/RP for the children with ADJ, but the direction is determined because of the high loading for Age. For older children, ∠SN/OP is small, ∠SN/RP is large, the gonial angle and ∠RP/OP are small and the corpus is large.

9.4.4 FACIAL HEIGHT

Table 9.10 Comparison of the loadings from the different analyses for the factor FACIAL HEIGHT.

	R	S	O	ADJ
∠ SN/FH				– –
∠ SN/PP				
∠ SN/OP		+		
∠ SN/MP	+			+
∠ SN/RP	+			
Gonial angle				
∠ RP/OP				
∠ S-N-Pg				
∠ A-N-Pg		+		
∠ S-N-A				
∠ Ba-S-N				–
Y-axis	+ +	+ +	+	+
TFH	+ +	+	+	+ +
UFH				
LFH	+ +	+	+ +	+
PFH				
S-N				
S-Ar				
Ar-N				
S-Gn				+
Ar-Gn				
Ar-Pg				
Ba-Gn				
Ba-Pg				
Gol-Gol				
Overjet			–	
Overbite			– –	
Gol-Pg'				
Ar-Gol				
Pr Ba-Pg/OP				
Pr Ar-Pg/OP				
Pr Ba-Gn/OP				
Pr Ar-Gn/OP				
AGE	320	–153	–116	208
SEX	–122	–532	71	189
Appliance	141	–354	457	129

In the table are presented the factor loadings at year 0 for the children without temporomandibular joint dysfunction, the children with purely subjective symptoms, with purely objective symptoms, and with ADJ; ++ or –– corresponds with a factor loading of 0.7–1.0, + or – corresponds with a factor loading of about 0.5–0.7.

This factor has a very definite relationship with the total face height. The reverse relationship with the overbite is not totally unexpected. The distributions of the loadings for the different groups of children are more similar in this factor than in any of the other three.

9.5 Discussion

One of the possible methods for discovering structural relationships in a set of variables is factor analysis. In this procedure, individuals who are characterized by a large number of variables are described with a limited number of factors, within which the original variables are grouped into clusters.
There are several limitations inherent to factor analysis and these must not be underestimated. For example, the formation of a factor is dependent on the original number of variables used to characterize the individual. If two factor matrices were to be formed where the second differed from the first in that several highly charcteristic variables had been added, then the two matrices would also be different. Additionally, the possibility exists that in the first matrix a factor will be improperly assessed because of the absence of essential characteristics.
The advantages, on the other hand, are that the reductions made possible by the method make a structure in the set of variables perceptible without sacrificing too much substantial information. The variables within one factor exhibit a relationship with one another by forming clusters of high loading variables. This provides vital information about which structural relationships are present in the set of variables.

The great strength of factor analysis lies in the possibilities it affords for finding interpretations of these structural relationships –that is, for setting up models to explain them. This is made more difficult by the fact that a number of choices must be made when employing factor analysis for which no consistently applicable set of criteria is available. It is then primarily important to try to ascertain why the clusters were formed. The variables Age and Sex can be expected to underly the formation of factors. Yet other factors may be determined by variables which clearly vary in time, or which are larger for boys than for girls, but for which the cause of the formation of the cluster must be sought elsewhere than in age or sex. This cause is then stronger than the effect of age and sex. In such cases it will not be immediately obvious why a variable assumes a large or a small value.

When for the sign + or – of a certain loading is filled in large or small, then the opposite must also be done consistently. **It must constantly be remembered that the loading of a variable forms a balance: there are per definition both large and small dimensions which determine the relationship to the cluster; it is not the absolute size which is important, but the relative value within the group of individuals for which the factor analysis is carried out.**

When in certain cases the cause of the cluster forming can be pinned down, then the proper interpretation is also evident. This is certainly true of the factors in which Age has a high loading. The largeness or smallness of other high loading variables varies concurrently with the Age's being young or old; the cause –age– is known, the interpretation –growth– is obvious.

The only literature, as far as we could ascertain, where factor analyses was applied for growth variables Y, was the work of Solow (1966, 1967, 1970). There are, however, several basic differences between his factor analyses and ours, which frustrate comparison. First, Solow's material is derived exclusively from adult men; this means that no definite contribution of the variable Age can be expected toward variation in size of the growth variables Y. Secondly, that author does not distinguish any groups within the sample whose factor matrices can be compared. Thirdly, Solow includes in his growth variables Y dimensions –the length of the Humerus for example– which were not measured in this study. This creates problems, as evidenced by the fact that the percentage of variance explained in his analysis, as computed (by us) for the purpose of comparison, was 44%. In the fourth place, there are usually twenty or more factors rotated in Solow's analyses, which means that the causes of cluster formation must remain at times unknown. Finally, Solow has strived for simplification by reducing –in an elegant formulation– the number of variables, while simplification is sought in this study through a considerable reduction of the number of factors to be rotated.

A procedure has been followed here which is analogous to the one commonly used in the social sciences: the number of factors was limited –in this case to four– and a name was given to these factors which described their content. Using the factor matrix for children without temporomandibular joint dysfunction at year 0 as a reference group, and following the general method described above, the following four factors were named:

- the factor SIZE
- the factor SHAPE
- the factor MANDIBLE
- the factor FACIAL HEIGHT

Factor matrices were then set up for the group of children with purely subjective symptoms, for the group of children with purely objective symptoms, and for the children with ADJ. There was often a large measure of agreement among these matrices for factors bearing the same name.

The factor SIZE consisted entirely of linear dimension whose size was related to Age. The dimensions were larger for the older children than for the younger ones. The anticipated relationship with sex –girls, after all, have smaller skull dimensions than boys– did not appear. The presence of the angular measurement ∠S–N–Pg is striking in the matrices of the children with purely objective symptoms and with ADJ. Apparently, the behavior of this angular measurement was the same as the linear measurements. An attempt has been made to formulate an explanation of this phenomenon, at least as far as ADJ is concerned, in Chapter 10.

The factor SHAPE, except in the case of the children with ADJ, was clearly related to the angular measurements which contribute to the determination of the profile. Although it is now certain that a strong relationship exists between the angle formed by the junction of the Occlusal Plane and the Palatal Plane with S–N, ∠S–N–Pg and ∠S–N–A, the background of this relationship is not understood. For the children with ADJ the factor was related to sex; the distances S–N, S–Ar and Ar–N were greater for boys than for girls.

The factor MANDIBLE was determined primarily by the angular measurements of the mandible. It is significant that the angular measurements of the Mandibular Plane and the Ramal Plane usually were not represented in the same factor. The anticipated relationship between these measurements and ∠A–N–Pg was only present in the reference factor matrix. For these children and for those with ADJ, the loading for Age was high enough to allow an interpretation according to age.

The factor FACIAL HEIGHT was the most homogeneous. Total Face Height and Lower Face Height and the Y–axis demonstrated relationships; however, the anticipated relationship with overbite was lacking for the reference group children, the group children with purely subjective symptoms and for those with ADJ.

It is interesting that, with two exceptions, ∠SN / RP and ∠SN / MP both never received a high loading together in one factor. This means that both angles can change independently of each other depending on the circumstances. This is consequently also true for the gonial angle. This conclusion may provide a link with the theory of the functional matrix which states that corpus and ramus form different relatively independent functional components (Moss 1962).

To summarize, factor analysis has laid bare a structural relationship in the various growth variables Y which has not yet been described. Applying the technique to different groups makes it possible to make comparisons. It therefore makes an important contribution toward the explanation of mutual relationships among craniofacial patterns and influences exerted upon them.

Chapter 10

Synthesis of the results of the investigation

10.1 Introduction

In this chapter a description is given of how the results from the regression analysis and factor analysis can be combined. The presence of a relationship is also asserted between the different types of growth rotations of the mandible (Björk 1963) and malocclusions. In addition, the relationship between a strong forward growth rotation and purely subjective symptoms is discussed, as well as the relationship between backward growth rotation and trauma and ADJ. From these analyses there flows a hypothesis about the way in which the mandible can compensate for a lack of growth potential of the condyle. Finally, some remarks are made about the role played by the condyle in the chain of factors which determine the growth pattern of the mandible. The questions posed in Chapter 1 are answered.

10.2 Growth of the mandible

How to interpret cephalometric data has been a sizeable problem for researchers and clinicians for years.
The studies of Björk (1955, 1960, 1963, 1972) have provided valuable information about the way in which the craniofacial complex grows. His metal implant method is particularly well suited to demonstrating individual variations. The results of his investigations of mandibular growth are especially noteworthy. In some cases a growth rotation of the mandible becomes evident. The role which the direction and degree of condylar growth plays is much better understood as a result of Björk's studies.
Rotation of the mandible can only be precisely registered by using metal implants. When no implants have been placed, an impression can be gained of the size and direction of this rotation by superpositioning cephalograms taken at different times on more or less stable structures: tip of the chin, inner cortical structure at the inferior border of the symphysis, trabecular structures related to the mandibular canal and the lower border of the third molar germ. This is called structural superpositioning (Björk 1969).
Björk distinguishes three types of growth rotations:

forward rotation (negative) with a rotation center at the lower incisor, forward rotation (negative) with a rotation center at the premolars, and backward rotation (positive) with a rotation center at the occluding molars.
As a result of this growth rotation the condyle usually undergoes greater growth changes (depending on the type of rotation) than the individual superpositioning on contours would lead one to believe. This is clarified with Figures 10.1 and 10.2. Figure 10.1 is the structural superposition (on metal implants) and is taken from "Variations in the Growth Pattern of the Human Mandible: Longitudinal Radiographic Study by the Implant Method" (Björk 1963). The adaptation made in Figure 10.2 is a superposition which is based on a recommendation by the Workshop on Cephalometrics (Salzmann 1960).

Although Figure 10.1 is the only correct one, in Figure 10.2 it is easier to see how much the mandible has been enlarged through growth. In fact, the effect can be seen and conceptually visualized better in Figure 10.2. In Figure 10.1 are portrayed the total

Figure 10.1 Borrowed from Variations on the Mandibular Growth Pattern *(Björk 1963). This rotation developed over a period of 6 years.*
Superpositioning on metal implants reflects an exact and biologically correct growth pattern. The arrow represents the actual –taken place– condylar growth.

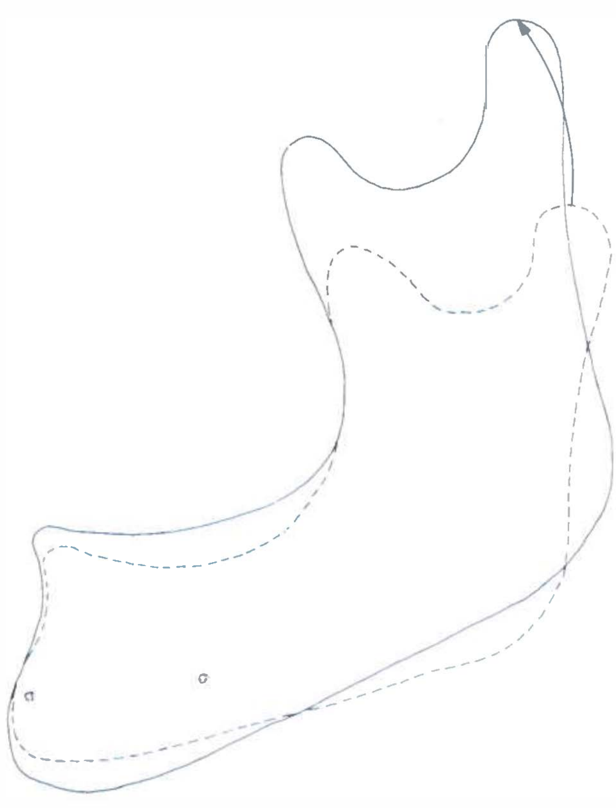
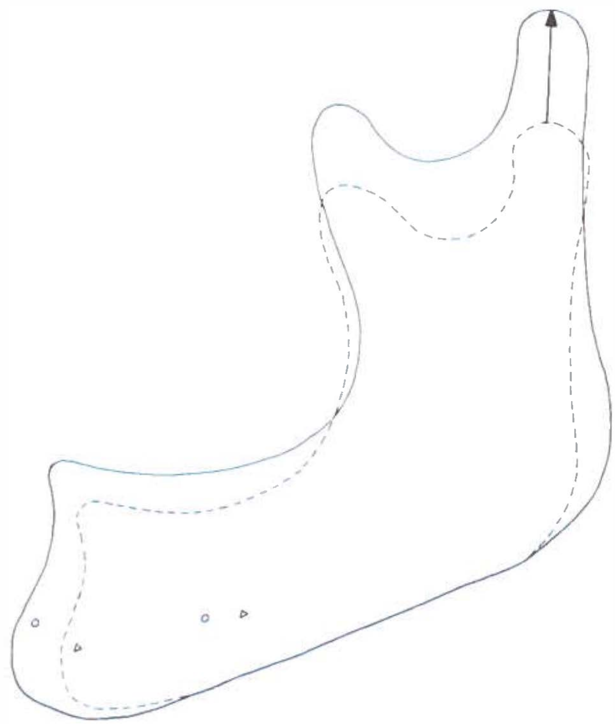


Figure 10.2 Superpositioning of the two tracings from Figure 10.1 on the middle of the lower border of the mandible, as suggested by the Workshop on Cephalometrics (Salzmann 1960). This type of superposition is incorrect, but it does make it easy to see how much larger the corpus and ramus become (arrow).



growth changes which the condyle undergoes in the six years which have elapsed between the first and the second cephalogram, as derived from structural superpositioning.
This growth of the condyle largely originates from the proliferation of the condylar cartilage. It is therefore not itself displaced by the rotating mandible, as a static analysis of Figure 10.1 would lead one to believe. A comparison of cephalograms taken at different times also gives no idea of what changes have taken place. It can therefore be seen that the interpretation of measured changes in a series of longitudinal cephalograms, using the conventional cephalometric landmarks, can only proceed with the greatest of care. Growth can have occurred, while its result cannot be seen on the cephalogram, or fully derived from measurements.

Seen in an historical perspective, it is understandable that it has taken so long for an insight to be gained into facial growth patterns in humans, since the results of growth studies with metal implants in animals (Robinson and Sarnat 1955; Bodegom 1969;

McNamara jr. 1972) demonstrate hardly any mandibular growth rotation. The background of these processes of growth rotation is complex. Several different factors and conceptions are presented (Enlow 1975²; Moss 1972).

The growth pattern of the mandible is the result of differential apposition and resorption on all the periostial and endosteal bone surfaces and chondrogenesis and endochondral ossification in the condyles (Enlow and Harris 1964). Growth rotations, as described by Björk, are the result of a specific coordination of apposition, resorption and condylar growth. Numerous experimental studies (among others Koski and Makinen 1963; Duterloo 1967; Duterloo and Wolters 1972; Moffet 1972; McNamara jr. 1972, 1975; Petrovic *et al.* 1974, 1975) have shown that the degree and direction of chondrogenesis in the condyle can be strongly influenced by mechanical or functional factors.

The total facial growth pattern is determined by a number of factors which influence one another. It is clear that when one factor is disturbed, a large number of compensatory reactions are evoked. The group with ADJ is a good example of this. This deformity involves a chronic, pathological process in the condyle which evokes specific compensatory responses which will be described later in this chapter. Other factors which disturb the condylar chondrogenesis will also initiate these compensatory processes.
Finally, it should be noted that in the process of all these complex changes, the mandible as a whole more or less retains its original shape. Sequential superposition of separate parts of the contours gives better congruency than superposition of the whole. This is supported by the observations of Brodie (1941) and Kraus *et al.* (1959).

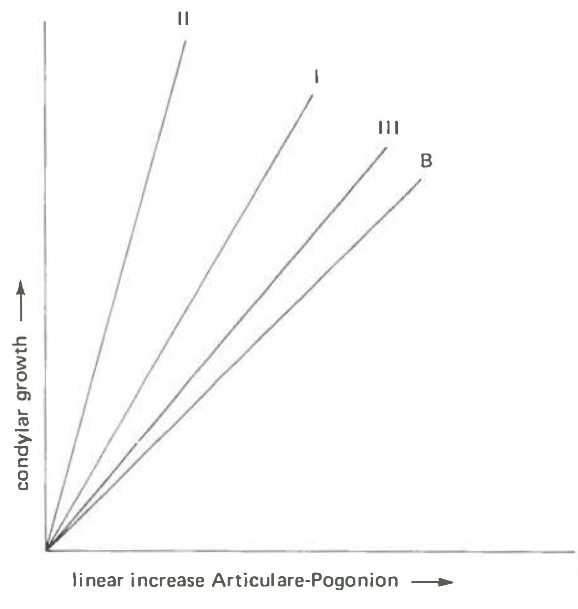
10.3 Displacement of the mandible

The results obtained from the various methods of superpositioning the mandible on cephalograms have shown that the growth of the condyle has at least **two** effects: growth rotation and enlargement.

Rotation of the mandible can only be precisely registered by using metal implants. Enlargement of the mandible as a whole is expressed, for example, in the lengthening of a diagonal through the mandible: Articulare–Pogonion is one possibility (Tofani 1972). The effect of the growth of the condyle also finds expression in a linear increase of Ar–Gol, the ramus, and/or Gol–Pg', the corpus. However, considering possible remodeling changes (for example, through the formation of a gonial notch), a diagonal is a more sensitive measure than Ar–Gol or Gol–Pg' for the registration of an enlargement of the mandible.
Part of the linear increase of the diagonal is needed to keep pace with the displacement of the maxilla.
Another aspect of the linear increase can in certain cases result in the mandible's being displaced anterior to the maxilla.
No sharp distinction can be made between the results of remodeling and condylar growth on the one hand, and displacement which appears as a result of this growth and remodeling on the other. This should be considered when examining both Figures 10.1 and 10.2.
Computing a projection of Basion–Pogonion, for example, on the Occlusal Plane, can give some impression of the amount of total displacement of the mandible. The projection, rather than the dimension itself, must be computed because the mandible will shift along the Occlusal Plane (Chapter 5).

It is assumed that there is a relationship between condylar growth, measured by using metal implants, and a linear increase in the diagonal Articulare–Pogonion. The exact nature of this relationship cannot be determined from the data available from this study. It can be stated that condylar growth does not always contribute to the extension of the diagonal Articulare–Pogonion to the same degree, but that this linear increase is partially determined by the direction of growth. Both factors, direction of growth and rate of growth, thus influence the linear increase of Articulare–Pogonion. This is graphically presented in Figure 10.3.

Figure 10.3 Hypothetical figure, in which the contribution of condylar growth to the linear increase of the diagonal Ar–Pg is depicted.
The bisector B indicates the limit of the contribution of condylar growth to the linear increase of Ar–Pg.



The bisector B shows the limit of the contribution of condylar growth toward the linear increase of Ar–Pg. The –arbitrary– location of line III represents the relationship for an Angle class III malocclusion in which the total condylar growth primarily contributes to the linear increase of Ar–Pg. The direction of growth is in a direct line with this diagonal.
The –likewise arbitrary– location of line I represents the "normal" relationship between condylar growth and the linear increase of Ar–Pg.
The line II[1] must have a steeper slope than line I, because with an Angle class II, division 1 malocclusion the mandible rotates, but the linear increase of Ar–Pg is less than the increase of the other craniofacial dimensions. The mode of condylar growth is anterosuperior.
With the aid of Figure 10.3, three facial growth trends are distinguished which correspond to the Angle classification of orthodontic anomalies.

Angle class I : there is harmony between condylar growth and the linear increase of Ar–Pg; there is a slight rotation.
Angle class II : there is disharmony in the development of the craniofacial structures, localized primarily in the mandible. Ar–Pg clearly lags behind. Considerable rotation occurs.
Angle class III: the development of the mandible is largely in an anterior direction. Condylar growth is utilized fully to cause Ar–Pg to increase linearly.

A totally different type of factor in addition to rotation, can influence the distance Articulare–Pogonion. The landmarks Articulare and Pogonion can also change their positions independent of growth rotations. A review of the positional changes of these two landmarks follows below.

Pogonion can change its position in relation to the surrounding structures in four ways, independent of a contribution from the condyle. These are:

a. Displacement of the mandible as a whole. This could happen for example, if the joint changed its position.
b. A larger gonial angle, with a resultant increase in the length of the diagonal.
c. Apposition at the area of Pogonion.
d. Apposition along the entire posterior border of the ramus.

It is known that the relative position of the Fossa and the articular tubercle compared to the rest of the craniofacial structures changes as a result of growth of the cranial base and the middle cranial fossae (Enlow 1975[1]).
An enlargement of the gonial angle is a possibility for a displacement, supposing that it does not subtract from the height of the corpus or the width of the ramus.
The apposition in the area of Pogonion is very limited (Björk 1963). The unusual occurrence of apposition along the entire posterior border of the ramus is sketched in Figures 10.4 and 10.5. The mandibular tracings of two children, made during four successive checkups, are superpositioned in these figures, using the structural method.

Figure 10.4 Superpositioning of 4 consecutive mandibular tracings on relative stable structures. The cephalograms were made at the yearly checkups. There was a trauma of the chin, but there was no temporomandibular joint dysfunction.

C.R. ♂ 5528

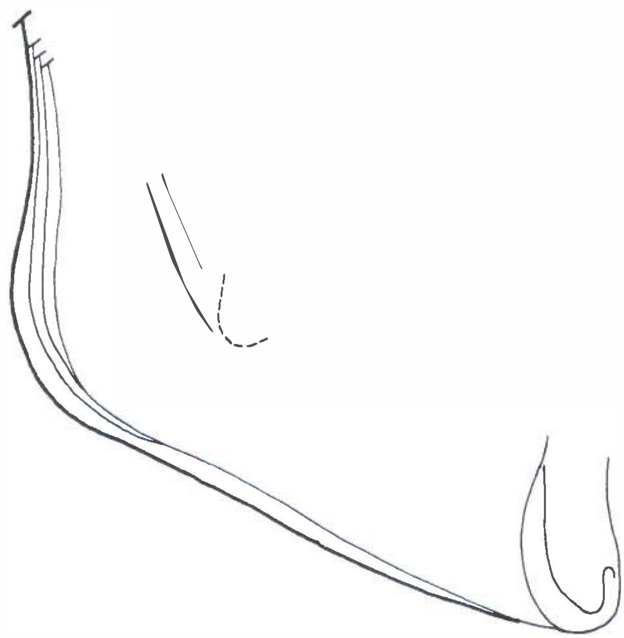


Figure 10.4 concerns a boy for whom a trauma was recorded in the case history, but for whom no temporomandibular joint dysfunction was observed during any of the checkups.
Figure 10.5 concerns a girl with ADJ but without trauma in the case history. Severely deformed condyles were already visible on the Parma radiographs at the first checkup (year 0) (Figures 1.4 and 1.5).
As a comparison, the more usual forward growth rotation is shown in Figure 10.6. This was recorded for a boy without temporomandibular joint dysfunction, who responded well to activator therapy. The time lapse between the two radiographs was three years. Totally different growth patterns are evident from the Figures 10.4 to and including 10.6. The mandibular

Figure 10.5 Superpositioning of 4 consecutive mandibular tracings on relative stable structures (Björk 1969). The cephalograms were made at the yearly checkups. Highly deformed condyles were visible on the Parma radiographs beginning at the first checkup (Figures 1.4 and 1.5). There was no trauma in the case history.

J.H. ♀ 5979

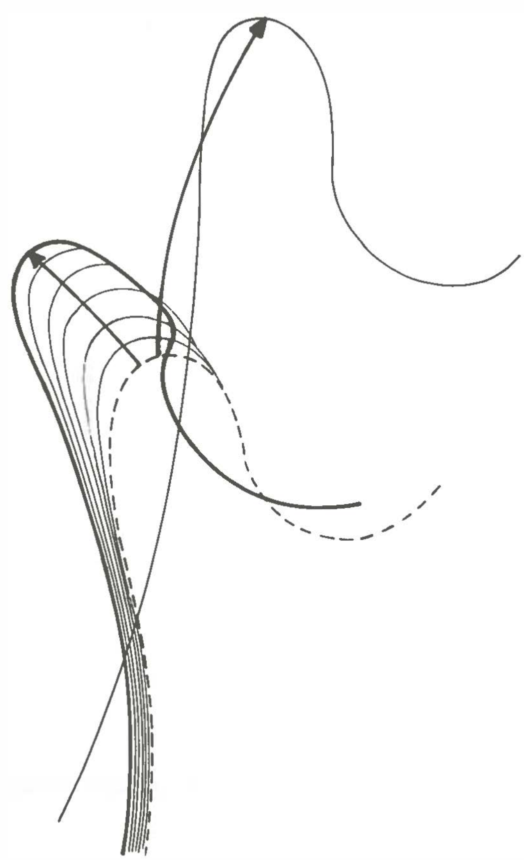
growth pattern illustrated in Figures 10.4 and 10.5 is similar to several cases described by Björk and Skieller (1972). These authors describe twenty-one cases which were evaluated using the metal implant method; two of these cases (cases 2 and 4) were clearly different from the other nineteen. These two were the only ones in the group under study to exhibit a backward condylar growth ("backward curved path of condylar growth" loc. cit. pg. 372, or positive rotation). Björk and Skieller write of these two cases: "In case 2 and 4, with a backward rotation of the mandible, there is a remodeling in the opposite direction, characterized by only slight apposition below the symphysis and the anterior part of the lower border of the mandible. Marked apposition below the angle, on the other hand, gives rise to increased convexity in this area" (loc.cit.pg.370). The plates of these two cases demonstrate that there is, in fact an enlargement of the gonial notch.

An indication was sought for the development of such a definite gonial notch with ADJ (and sometimes with trauma). It is evident from the previous discussion that mandibular growth is sometimes different, in the sense that the condyle grows posteriorly without

Figure 10.6 Superpositioning of 2 mandibular tracings on relative stable structures (Björk 1969). The cephalograms were made with an interval of 3 years. There was no trauma in the case history and there was no temporomandibular joint dysfunction.

R.S. ♂ 5914

Figure 10.7 The difference between an anterosuperior and a posterior condylar growth pattern. A hypothetical construction.



contributing any definite growth rotation. This contrasts with an anterior growth component which can result in a marked rotation.

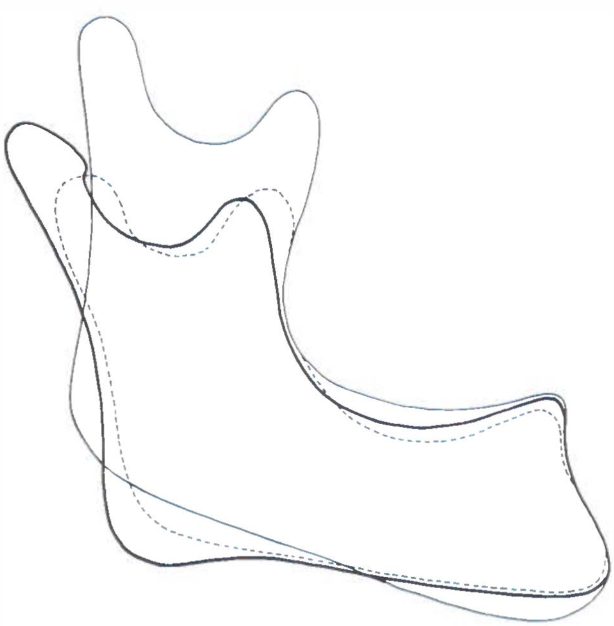
The hypothetical construction of a mandible in the children with ADJ or with a trauma must then be based on this weakened rotation. Additionally, Figure 10.5 shows that in this clear-cut ADJ case the condyle does not contribute to a linear increase of the ramus. Yet this mandible has to fulfill all basal functional requirements (Enlow 1975[1], 1975[2]; Moss 1972). The following characteristics must therefore be observed in the constructed mandible:

- linear increase of the diagonal
- no significant diminishment of the vertical increase of the ramus
- no diminished increase in the sagittal width of the ramus
- no, or hardly any, rotation.

When these conditions are met, Figure 10.8 results, which closely resembles the image produced by ADJ on the Parma radiograph.

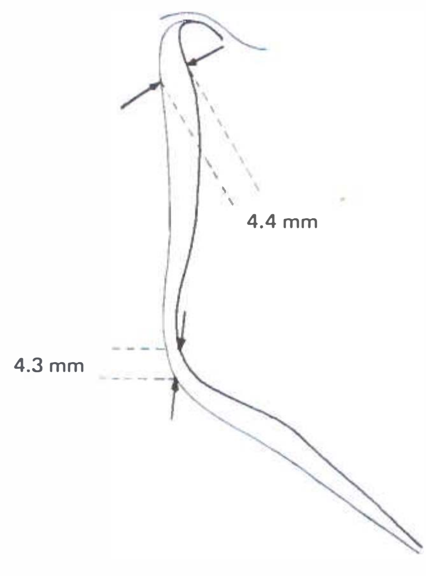
The condyle of children with a trauma in the case history did appear after all to contribute to the vertical development of the ramus. There was likewise no or hardly any rotation, but the formation of a gonial notch appeared to be dependent on the vertical development of the ramus, as illustrated in Figure 10.4.

Figure 10.8 Hypothetical construction of a mandible in which the condyle makes an insufficient contribution toward growth. The dotted line figure represents a mandible from a young child, the thin (rotated) figure represents how the image would have appeared after structural superpositioning and a normal development. The thick-line figure represents the mandibular development as it would have taken if condylar growth was diminished.



The factors which help to determine changes in the position of Pogonion have been analysed; changes in the position of Articulare will now be discussed.
One consequence of condylar growth rotations is a different projection of Articulare. When there is a marked forward rotation there will clearly be a growth component which is in an anterosuperior direction. As a result of this marked activity, the posterior border of the ramus will presumably be located more posterior to the articular tubercle. The intersection of the projections of the contours of the ramus and the cranial base, the landmark Articulare, will therefore lie inferoposteriorly (Figure 10.9).

Figure 10.9 Detail tracing of the position of the joint as it can be derived from Table 8.5.
From the figure can be seen how most of the differences between the children with purely subjective symptoms and children with ADJ at year 0 are apparently due to the change in the position of the condyle in the joint.



As a result of a completely posteriorly directed condylar growth, on the other hand –as occurs with ADJ– the ramus will be located anterior to the articular tubercle. This anterior displacement will be intensified by a flattening of the most anterior part of the head of the condyle appearing on the Parma radiograph. In the first case, the distance Sella–Articulare will increase; in the second it will decrease. This explains the results of the regression analyses in Chapter 8 (Table 8.5) where children with purely subjective symptoms were compared to children with ADJ. It was shown there that a computed distance of 4.4 mm exists between the mean positions of Articulare for the two groups.

As a result of these differing effects, the linear distances of the two projections will have a changing relationship to each other in time. This must be taken into account in making analyses where the position of Articulare is considered to be representative for the position of the condyle.
Finally, the variable length of Ar–Gol, the ramus, is the result of the variable position of Articulare. This dimension is namely determined not only by the length of the ramus itself, but also by the anatomical relationships present.
Due to the upward inclination of the pharyngeal contour of the spheno-occipital portion of the posterior cranial base, an anterior projected Articulare will be responsible for an increase in the dimension Ar–Gol, the ramus; the reverse is also true. This must also be taken into account in the interpretation of the results of these analyses.

10.4 Combined results of the statistical analyses

Results of the regression analyses and the factor analyses must be cautiously interpreted. Both are mathematical models and thus give a "preprogrammed" insight into the actual problem being considered. The two approaches can be roughly classified as quantitative for the regression analysis, where concrete measurements are computed for each variable, and qualitative for the factor analysis, which provides an insight into the structural relationships of all the variables taken together. Combination of the results of both types of analysis form a point of departure for a differential diagnostic analysis of the Angle class II, division 1 malocclusion based on the results of statistical research. For that reason the interpretation of the body of data was only carried out for the situation at year 0, the moment at which no orthodontic treatment had as yet taken place. Although the analysis and interpretation of the longitudinal data (comparison of year 0 with the other years) can be expected to deepen understanding of the processes that have taken place, it seems preferable to retain the restriction described above.
In the following discussion the results of the regression analyses –concrete measurements– are combined with the clusters of variables which received a high loading in the factor matrices, and among which there is a relationship. The group of children without temporomandibular joint dysfunction always served as a reference. The following names, describing the content of the high-loading clusters, were given to the four factors from the factor matrices:
- SIZE
- SHAPE
- MANDIBLE
- FACIAL HEIGHT

Cases where a significance level of $\alpha<0.05$ is exceeded are indicated with**; where a significance level of $\alpha<0.10$ is exceeded the indication is*.

10.4.1 Analyses for children with purely subjective symptoms

A mean (3.1 mm**) smaller dimension for Gol–Pg', the corpus, is in agreement with the less high loading –compared to the reference matrix– on the factor SIZE. A mean of 3.1 mm means that there are children with both smaller and larger dimensions. The mean (3.4 mm**) larger dimension for S–Ar is in this connection an indication of anterosuperior condylar growth; this is apparently accompanied by a marked forward rotation. The involvement of S–Ar with the factor SHAPE means that a larger dimension for S–Ar, and therefore a more marked rotation follows from a further receding of the chin. It does indeed seem that condylar growth that is not accompanied by a proportional increase in, for example, the diagonal Ar–Pg results in a marked rotation. It seems likewise to determine that the mechanism behind the factor SHAPE is dependent on the severity of the Angle class II, division 1 malocclusion.
The mean smaller ∠SN/RP (3.3°**), and the larger ∠RP/OP(2.9°**) are both connected with a more inferoposterior projection of Articulare. The higher loading –compared to the reference matrix– for Ar–Gol, the mandibular ramus, cannot be interpreted without reservations. The position of Articulare results in a relative shortening of Ar–Gol, the ramus, which conceals the actual length of the ramus.
In comparison to the reference matrix, the gonial angle exhibits a very high loading on MANDIBLE. A (3.6°*) larger dimension indicates a gonial angle which is larger then the average.

10.4.2 Analyses for children with purely objective symptoms

This group of children deviated the least from the children without temporomandibular joint dysfunction (reference group). There were only two distinct differences.
Angle ∠S–N–A was (3.0°**) smaller on the average for these children. Compared to the reference matrix, ∠S–N–A has a higher loading; the maxilla thus is strongly involved in the factor SHAPE. Specifically, the maxilla is retro inclined on the average. A mean dimension which is too large (1.7 mm*) for UFH, along with a high loading on the factor SHAPE opposite to

∠S–N–A, but equally directed to ∠SN/PP, indicates that a retro inclined maxilla is correlated to a more marked class II, division 1 malocclusion.

10.4.3 Analyses for children with ADJ

The largest and the most frequent deviations were observed in the regression analyses of these children compared to the reference group. The majority of these were included in the factor matrix of the factor SIZE.
Angle ∠SN/MP is (2.7°*) too large on the average. This means, of course, that both larger and smaller measurements were registered. The factor matrix shows why this phenomenon occurs. In the factor SIZE, ∠SN/MP loads exactly opposite to the other variables. That is, when the dimensions of these variables are larger, and the chin is in a more anterior position, then ∠SN/MP is smaller. This means that there is a more parallel course to S–N.
A situation in which there is a mean smaller dimension for S–Ar (1.2 mm*), and where S–Ar has a higher loading on a new factor which is related to sex, is similar to the situation illustrated in Figure 10.9. It would be difficult to make a more dynamic interpretation. Considering the high loading for sex, it is possible that Articulare is located more superiorly on the average for girls than for boys.
The less high loading for Age on the factor SIZE –in contrast to the high loadings in the other three matrices– points to a mechanism behind this factor, which is stronger than Age. Because only those variables which determine the position of the chin loaded high on this factor, and because of the similarity which was pointed out to the growth pattern in Figure 10.5, the conclusion can be reached that the determining factor here is the degree to which apposition takes place along the posterior border of the ramus. This thesis is supported by the very high loading for ∠S–N–Pg, which can occur when the mandible shifts straightforwardly. It appears here that the mandible is "attempting as well as it can" to compensate for the skeletal malrelationships. There may be some relationship between the failure of condylar growth and a high loading for Ar–GoI, the ramus; this high loading can be interpreted as partially the result of an anterior displacement of Articulare and an accompanying relative elongation of Ar–GoI.
The lack of a high loading on a factor matrix for a mean smaller PFH (3.4 mm**) and a larger overjet (1.3 mm*) may be a possible indication of an attempt to limit the perjorative effects of ADJ.

10.5 Concluding remarks

The preceding discussions permit that the following statements be made. From the total results it can be concluded that in cases of ADJ or trauma, the mandible develops an adapted growth pattern. This growth pattern must be seen as an attempt to continue to fulfill the basal functional requirements demanded of the mandible. Studies of entirely different deformities, such as cleft lip and palate, show that the craniofacial complex at least partially tries to express its original morphogenetic pattern (Van Limborgh 1966; Verwoerd- Verhoef 1974) according to an extremely complex regulatory mechanism, which is dependent on numerous factors.
Assuming that this multifactorial regulatory mechanism does exist, it can be posited that condylar growth performs an important function in this regulatory mechanism. Failure or diminishment of chondrogenesis in the condyle results in a specific adaptation of the pattern of apposition and resorption, in which the ramus and the gonial angle are primarily involved. The disturbance does not, therefore, lead to a retardation in the growth of the mandible. It should not, however, be concluded that therefore the chondrogenesis in the condyle plays an entirely subordinate role. Condylar growth does occupy an important place in a system composed of factors which all influence one another. This means that the condyle cannot be seen as an independent leader; it is leading, without being the leader.
Finally, it should be noted that a number of elements have been identified which can be valuable aids in making a significant, clinically applicable differential diagnosis. This is of primary importance for craniofacial growth predictions and orthodontic therapy.

The three different questions which the study sought to answer were described in Chapter 1. These questions were:

a. What is temporomandibular joint dysfunction?
b. Does a mandible become enlarged following the moment at which deformations of the condyle –ADJ– are ascertained?
c. Does orthodontic therapy cause ADJ?

Several statistical models were employed to answer the first question. It was demonstrated that there were already variations present before orthodontic therapy began within the total group of children with a class II, division 1 malocclusion; these variations were related in some way to abnormal mandibular growth. A part of this abnormal growth was caused by trauma of the chin in early childhood. The components of the group of symptoms usually described as TMJ dysfunction appear to be related to different craniofacial patterns. The differences between these components are so large that the use of the term "TMJ dysfunction" is to wide. Additionally, the categorization introduced in the study has deepened understanding of the meaning of symptoms and syndromes, in particular as concerns the further development which can be expected in the craniofacial skeleton (Chapters 8 and 9). Children with

ADJ and trauma were shown to have developed a distinctive mandibular growth pattern (Chapter 10).

The second question has also been answered. That is, when planning orthodontic treatment for a child with ADJ, it may be necessary to assume that the mandible is still growing. The mandible of children with ADJ proved itself able to develop in reasonably good harmony with the other craniofacial structures. Constant care must be taken in an orthodontic treatment to interfere as little as possible in this mandibular development.

The third question must be reasoned out before it can be answered.
The etiological factors causing ADJ are largely unknown. The results of this study, which tested many of the predisposing factors which literature has put forward as possible causes, cannot increase understanding in this area. The answer could have been found by comparing the number of children with ADJ before orthodontic treatment with the number with it after treatment. Such a comparison is, however, made virtually impossible by the lack of good and comparable control data from groups of children with a class II, division 1 malocclusion and with ADJ who received no orthodontic treatment.
And in addition, no objective morphological classification is available which discriminates the degree to which a joint has been affected. It would have been possible with such a classification to make judgements for each joint of the effect of therapy.
An opinion has been declared after all concerning the relationship, based on the three following considerations:

a. Sixteen percent of the children were determined to have ADJ at the beginning of orthodontic treatment. Considering that it has not been reported in dental literature, this percentage seems high. This percentage was 20% after one year of treatment and 24% after two years.
b. No new ADJ cases were diagnosed in the third or fourth year of the study.
c. It has been determined in Chapter 7, and especially in Figures 7.1 and 7.2 that the number of cases of ADJ increases after the children's twelfth year. It is thus to be expected that a group of children which is followed longitudinally will display more ADJ as they grow older.

Based on these considerations, the conclusion seems justified that the orthodontic treatment employed for these children was not a predisposing factor for ADJ.

Chapter 11

Clinical aspects

11.1 Introduction

This chapter describes how portions of the results and conclusions of this investigation can be used in clinical practice. The particular concern in this respect is the diagnosis and treatment of the Angle class II, division 1 malocclusion. When the study was originally set up –in 1968– little was known about temporomandibular joint dysfunction and its relation to craniofacial growth and orthodontic therapy. There was nothing to indicate that the different components which comprise temporomandibular joint dysfunction (definitions in Chapter 3) might have different effects on craniofacial growth; neither was this possibility taken into account in orthodontic treatment.

11.2 Case reports

The statistical analyses (Chapters 5, 8 and 9) showed that children with an Angle class II, division 1 malocclusion, who met the criteria for having temporomandibular joint dysfunction, had developed a craniofacial skeleton which was significantly different from children with a class II, division 1 malocclusion, but without dysfunction. Of the 112 children studied, about one half had temporomandibular joint dysfunction (Figure 8.1); half of this group had ADJ. The mandible in the group with ADJ had developed an unique growth pattern (Chapter 10). Children with a trauma in the case history had a mandibular growth pattern which closely resembled the ADJ pattern. Nineteen percent of the children fell into this group. An example is given from each of these three groups. In order to avoid differences which may be the result of the type of therapy used, the choice of examples was confined to those children who received activator therapy.

11.3 Angle class II, division 1 malocclusion, subdivided

The group under study is divided into five groups:
children with purely subjective symptoms,
with purely objective symptoms,
with ADJ,
with a trauma in the case history and
without temporomandibular joint dysfunction.

The significance of this division for growth prediction and prognosis is discussed in section 11.4. An example from three of these groups is given in the case reports. The clinical examination took place in the following way for these five groups:

11.3.1 Purely subjective symptoms (12% of the study group)

Complaints of pain indicated by the child, a click or a snap eminating from the joint or restricted mobility were usually only made after repeated structured interrogation. While the case history was being composed, questions about snapping were posed in a number of different ways. It was asked whether or not the joint sometimes made a noise, or if the children had heard a snap, or if they had ever heard any strange noises while chewing, or if it sometimes felt as if there were sand in the joint, etc. It was important that the joints be palpated first with some pressure while the child opened and closed the mouth, so that the child could feel the condyle moving and would know exactly what was meant.
When the answer to any of the above questions was in the affirmative, when no deformity was observed on the Parma radiograph, and when there was also no indication of trauma, the child was classified in the category with purely subjective symptoms.

11.3.2 Purely objective symptoms (15% of the study group)

These were ascertained by precisely palpating both temporomandibular joints. The mouth had to be opened as far as possible and then closed. A snap did not have to accompany every movement. However, the snap always occurred at the same moment in the open-close cycle. A snap was usually felt so clearly that no doubts could possibly arise. It is very interesting that in many of such cases the children were not conscious of the snap as such, and considered it to be "normal". When a snap was certified, and there were no deformities visible on the Parma and indication of trauma was also lacking, the child was classified in the category with purely objective symptoms.
During adaptation and analysis of the material it became evident that the dimensions and the position of the mandible did not differ significantly from the children without temporomandibular joint dysfunction. However, ∠S-N-A was 3° smaller on the average and the Upper Face Height was 2 mm greater. The true implications of these data are not clear.

11.3.3 ADJ (24% of the study group)

The symptoms described in literature such as snapping in the joint, pain and restricted mobility were often

present, but could also be completely absent. The X-ray image is described in section 3.2.1. The diagnosis could be established per definition only from an X-ray. The condyle on the Parma was usually so deformed that no doubt was possible. Although no significant relationship with trauma was demonstrated, the diagnosis ADJ prevailed when both trauma and a deformed X-ray image were recorded.
The diagnosis can best be established from the Parma radiograph. In the making of this radiograph the central beam runs through the extension of an axis through both mandibular condyles. The film cassette is pressed against the cheek on the side being X-rayed; the focus must be near the condyle on the opposite side. The mouth must be maximally opened when the radiograph is taken. The making of a (good) Parma radiograph can only be entrusted to a specialized X-ray photographer. The orthopantomogram is an alternative. This should be adjusted in such a way that the condyles are clearly projected. The disadvantage of laminagraphy, however, is that the section which is the most well-defined does not always include the place where the deformity is most pronounced (Eckerdal 1973). Also, the condyles can be distinguished very well on a cephalogram, with good contrast quality, and for which the mouth is maximally opened. An obvious disadvantage of this method is that the condyles -because of a focus which is relatively too far removed- are projected on top of each other.

11.3.4 Trauma (19% of the study group)

A trauma of the chin was registered for 19% of the children in the study. Parents' memories often were jogged only after repeated questioning by the investigator. A scar on the chin helped to refresh their memories in a large number of cases. When deformations were ascertained from the Parma the diagnosis of ADJ prevailed.

11.3.5 Children without temporomandibular joint dysfunction (54% of the study group)

A group of children remained who, when examined, proved to have no symptoms of temporomandibular joint dysfunction. This category thus came into being through the exclusion of all the other possibilities. Again, however, it should be remembered that all children had an Angle class II, division 1 malocclusion.

11.4 Growth prediction and prognosis

The establishment of a diagnosis is the most significant when it can be geared to a directed treatment plan and to the results expected from treatment. It is obvious that the results of this investigation, which was in fact directed toward a different topic, will permit only general observations about diagnosis and growth prediction. Yet they can provide an impetus toward finding the total complex of relationships binding the subgroups described, the craniofacial skeleton and treatment results.

None of the differences which distinguished the children with purely subjective symptoms at year 0 from the children without temporomandibular joint dysfunction (∠SN/RP, gonial angle, S-Ar and the ramus) still existed at the end of year 3. There were thus no differences between this group and the reference group children.

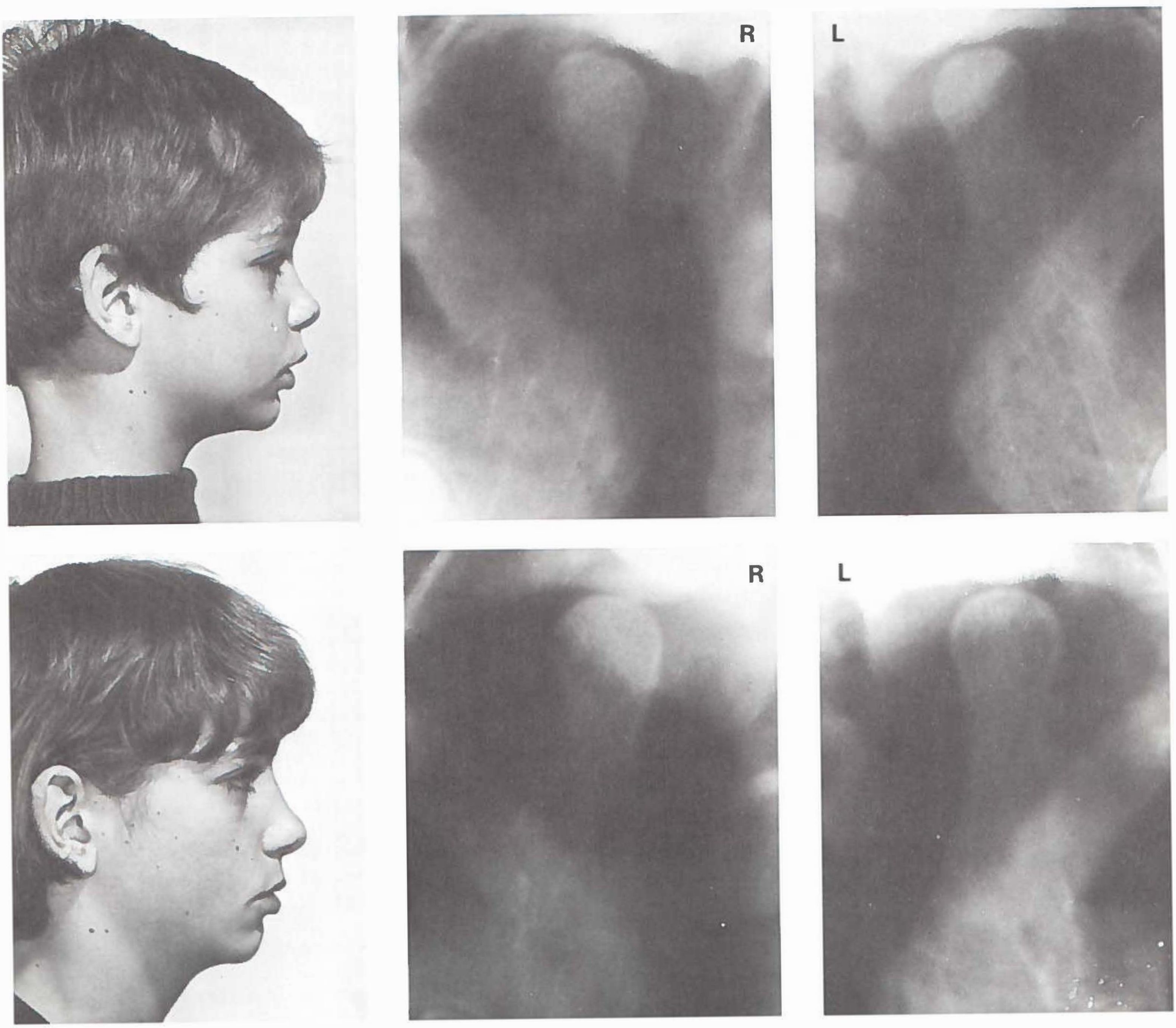
After three years there was a shift in the differences which existed between the children with purely objective symptoms at year 0 and the reference children (∠S-N-A and UFH). There were differences between the two groups in Gol-Gol and overjet at the end of year 3. The enlarged distance between the two gonial intersections may indicate a sagittal development of the mandible which is proceeding with some difficulty. The condylar growth and the resultant remodeling of the gonial angle is apparently not synchronous for left and right sides. Yet the results of Chapter 6 do not indicate that there is any systematic difference between left and right.

The differences between the children with ADJ and the reference children were the most distinctive. Apparently the joints whose X-ray image was clearly deformed exhibited little or no further growth in the vertical direction. The relatively limited progression of the deformity is in this respect an indication that when a certain nadir is reached, there is no further degeneration. This is the result of a number of compensatory possibilities, which are as yet incompletely understood. The mandibular growth which can still be expected to occur in these children is dependent on the degree of bone apposition which takes place posterior to the ramus, and finds its expression primarily in an enlargement of the corpus. The fact that PFH lags steadily further behind the normal growth pattern shows where these compensatory processes have failed. A steeper Mandibular Plane slope was a related phenomenon. The Mandibular Plane is defined in Chapter 2 as a tangent through point 9 (about at Menton) on the gonial angle. Results showed that it was exactly at this point that a marked apposition took place - the gonial notch was formed as a result; this meant that the corpus will be even steeper than this tangent. It is surprising that TFH was not aberrant as a result.

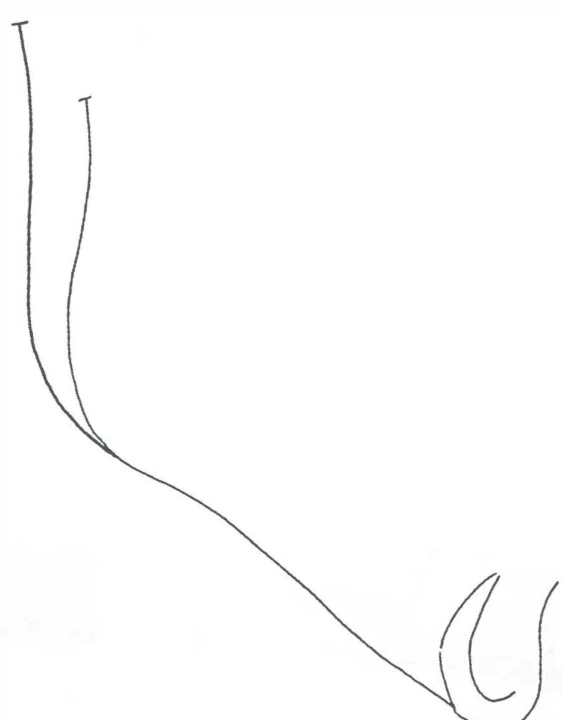
The enlarged total face height in children with a trauma of the chin, still evident at the end of three years, was striking.

All the deviations described above have been computed in relation to the children without temporomandibular joint dysfunction.

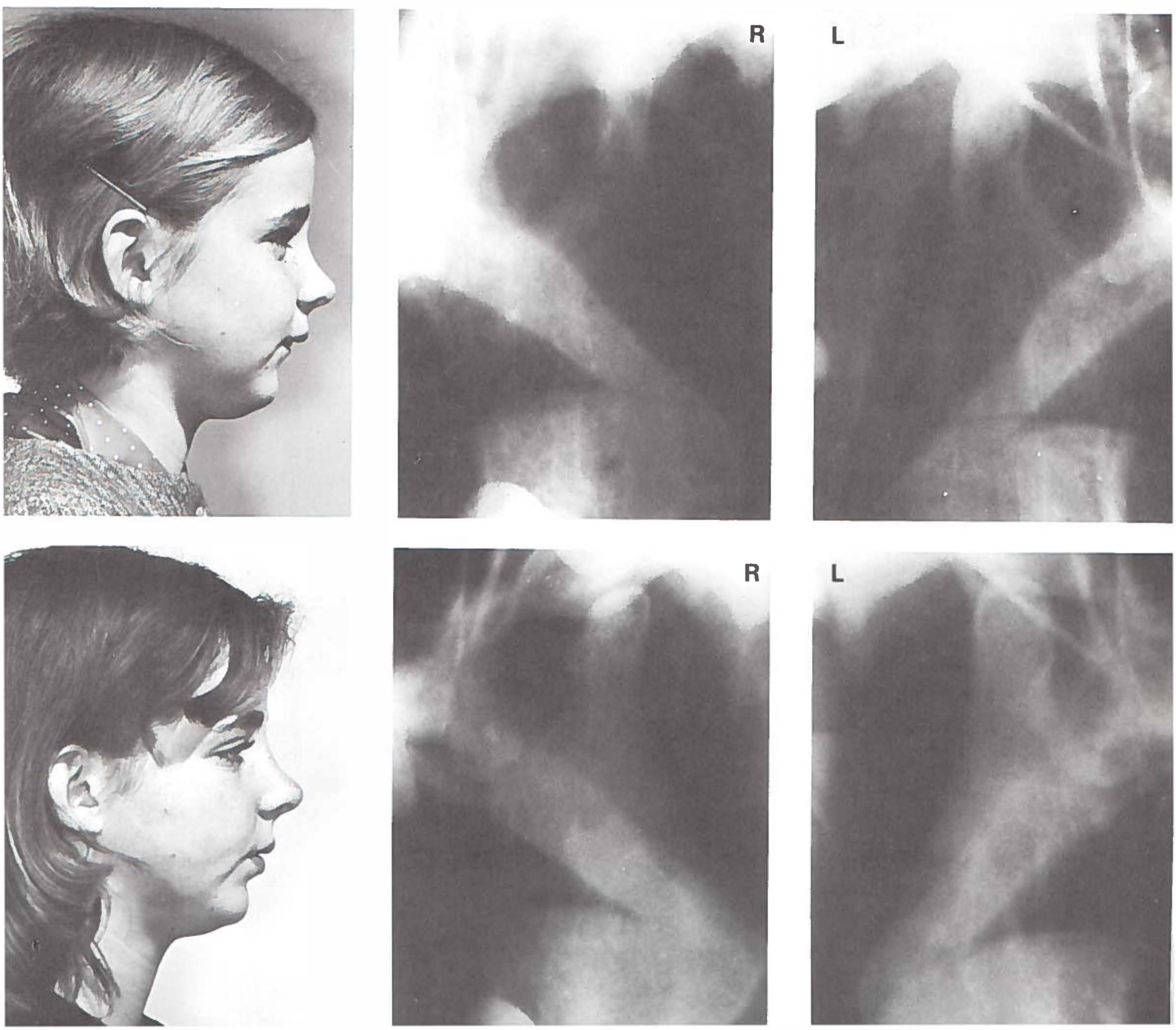
Case report 1. Figure 11.1
R.S. ♂ 5914 9.0 years old
No temporomandibular joint dysfunction; thumb-sucking until the treatment began; no trauma; time elapsed between the two cephalograms was thirty-six months; the total tracings are superpositioned on the anterior cranial base. The mandible is superpositioned in two ways: the structural method (Björk 1969) exhibits the rotation; the superposition on the symphysis and the lower border provides a better illustration of the increase in size. The Parma radiographs of year 0 and year 3 reveal excellent condyles.



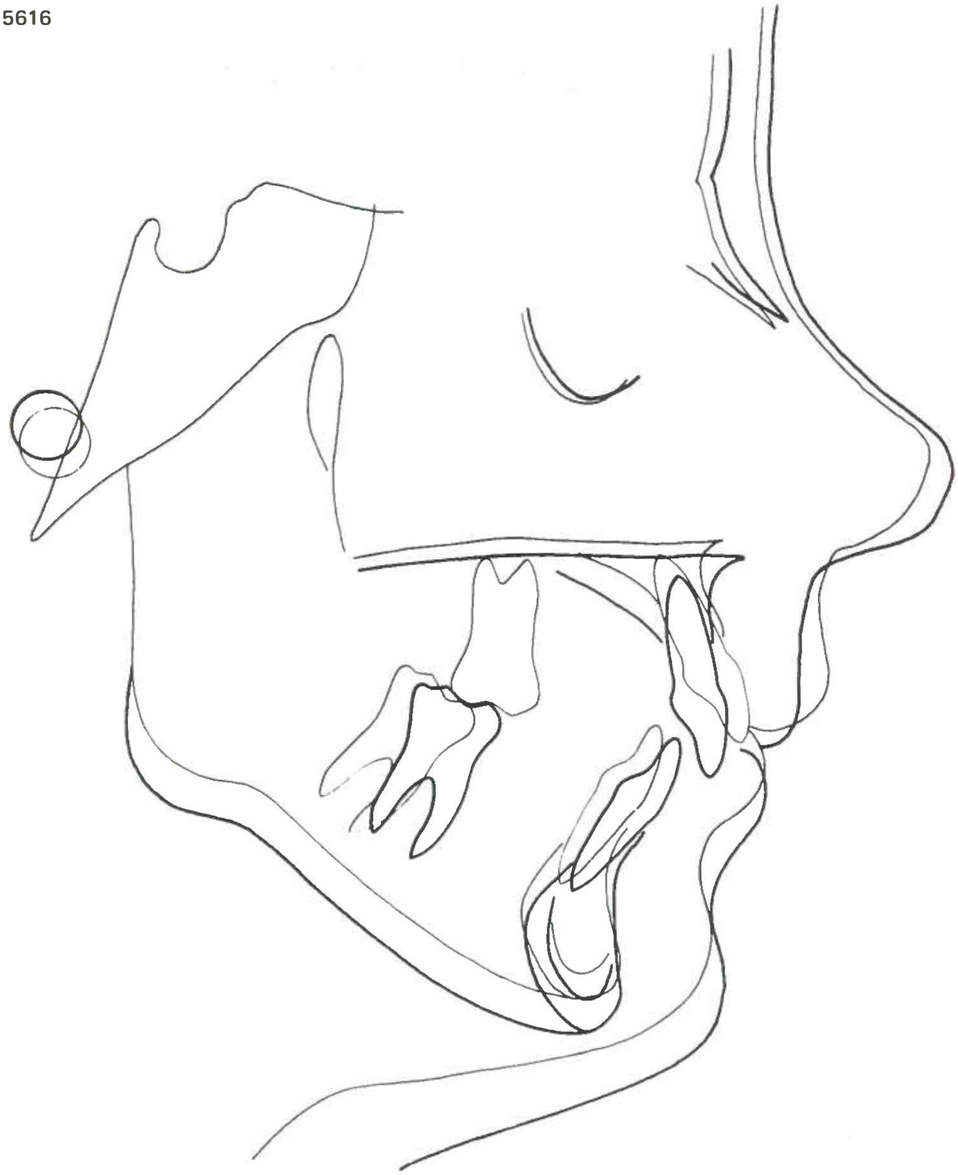
R.S. ♂ 5914

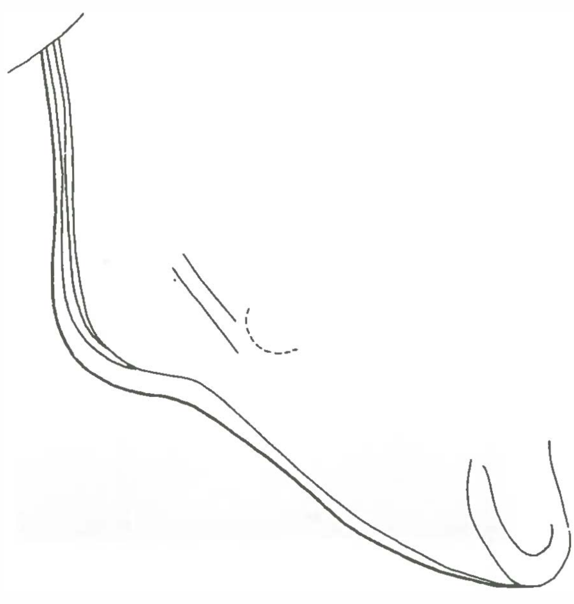


Case report 2. Figure 11.2
M.v.d.B. ♀ 5616 13.0 years old
ADJ; thumb-sucking to and including the last checkup; no trauma; time elapsed between each cephalogram was twelve months; the total tracings are superpositioned on the anterior cranial base; the mandible is structurally superpositioned; on the Parma radiographs at year 0 and at year 3 there is a clear deformation visible of the condyles of both left and right joints.

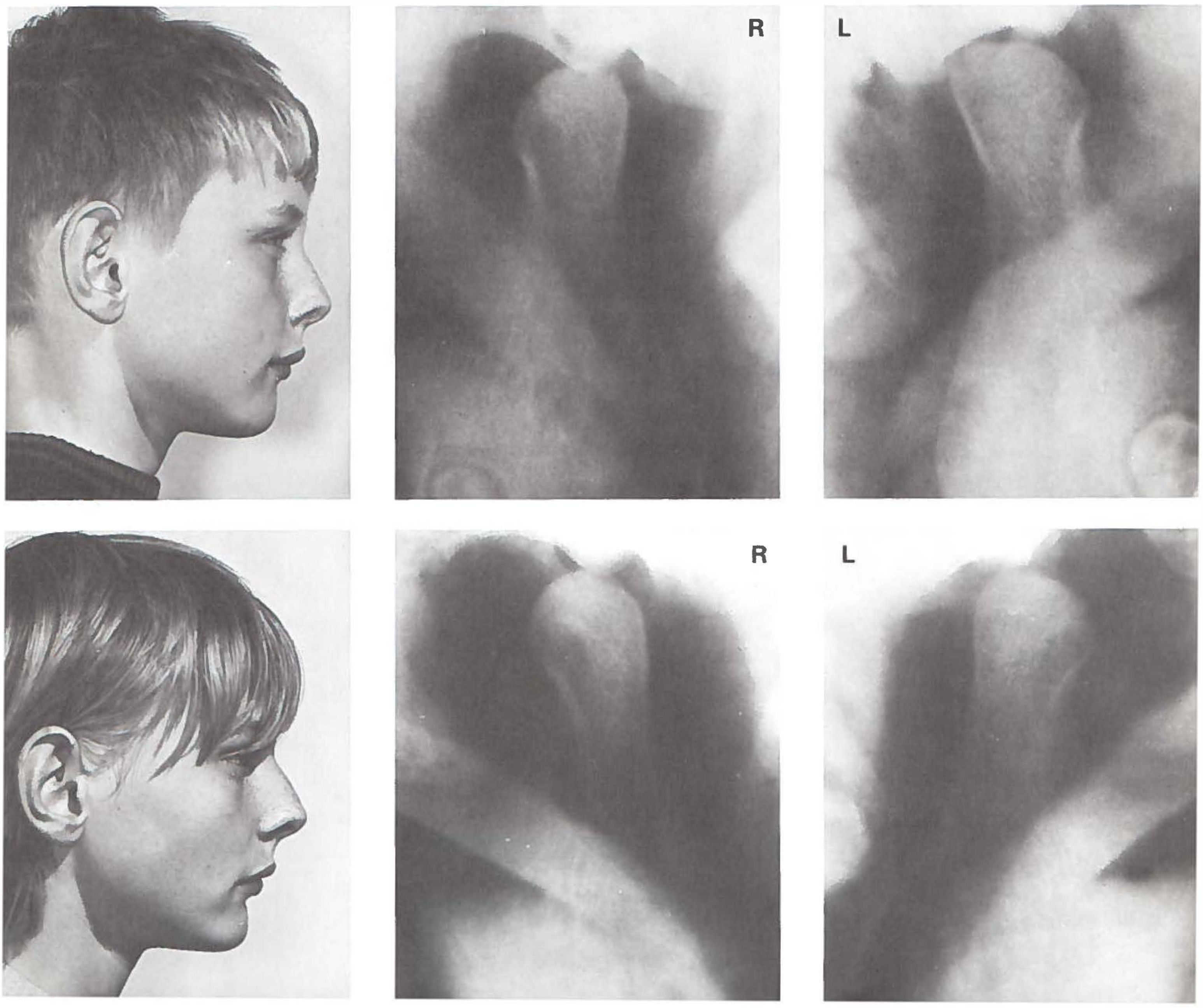


M.v.d.B. ♀ 5616

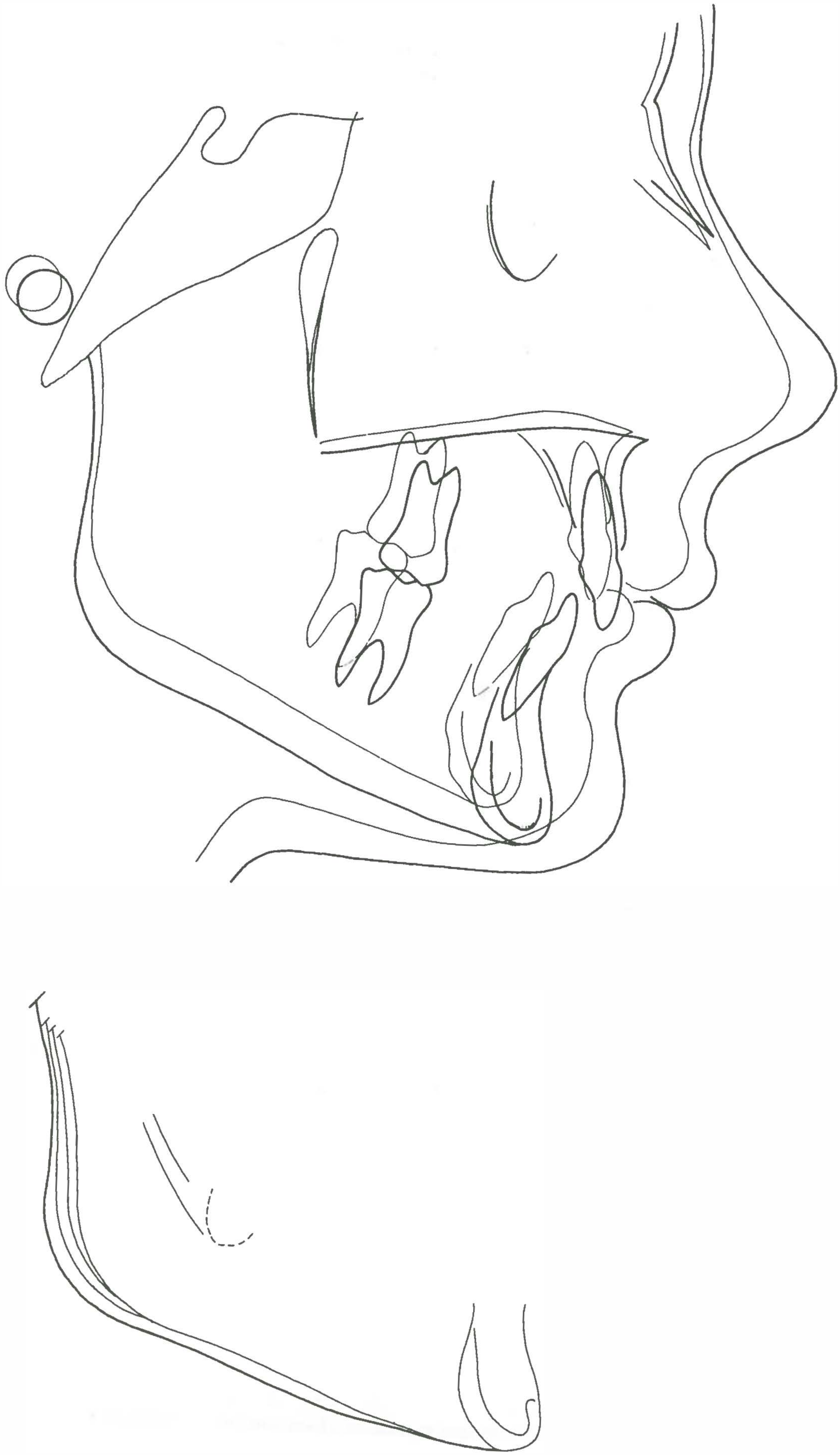




Case report 3. Figure 11.3
C.R. ♂ 5528 11.5 years old
No temporomandibular joint dysfunction; no abnormal oral habits; trauma of the chin (a severe fall in early childhood); time elapsed between each cephalogram was twelve months; the total tracings are superpositioned on the anterior cranial base; the mandible is structurally superpositioned; the left joint on the Parma radiograph at year 0 is malformed, there are no observable deformities on the Parma radiographs at year 3.



C.R. ♂ 5528



Samenvatting

Het doel van het beschreven onderzoek was inzicht te verkrijgen in de aard, het voorkomen en de betekenis van kaakgewrichtsafwijking bij kinderen met een Angle klasse II^{1} malocclusie om de invloed van die stoornissen op de groei van het aangezichtskelet te bepalen.
Het project werd opgezet als een interdisciplinair onderzoek van de afdelingen Mondheelkunde en Orthodontie van de Subfaculteit der Tandheelkunde van de Rijksuniversiteit te Groningen. De bewerking van het materiaal geschiedde in nauwe samenwerking met de Projectgroep Statistische Applicaties van het Universitaire Rekencentrum.
De vraagstellingen waren:

a. Wat is een kaakgewrichtsafwijking?
b. Wordt na het tijdstip, waarop op de röntgenfoto een sterke deformatie van het kaakkopje -Arthrosis Deformans Juvenilis- is gebleken, de onderkaak nog groter?
c. Kan orthodontische behandeling deze deformatie -Arthrosis Deformans Juvenilis- veroorzaken?

Honderdtwaalf kinderen met Angle klasse II^{1} malocclusie werden geselecteerd. De gemiddelde leeftijd bij het begin van de onderzoekperiode was 12,5 jaar. De eerste documentatie vond vóór het begin van de orthodontische behandeling plaats en vervolgens elke 12 maanden; elk kind werd minstens 4 maal gedocumenteerd. De orthodontische behandeling werd uitgevoerd met aktivatoren dan wel met vaste apparatuur volgens Begg.
De documentatie geschiedde door een op kaakgewrichtsafwijking gerichte anamnese en een klinisch onderzoek waarbij specifieke kaakgewrichtsopnamen volgens Parma gemaakt werden en een laterale en frontale schedelfoto. Ook werden lichtfoto's gemaakt.
De gebruikelijke cefalometrische technieken zijn toegepast voor het onderzoek van de craniofaciale groei. De selectie van de kinderen voor dit onderzoek en wijze van verzamelen en bewerken van de documentatie zijn beschreven in hoofdstuk 2.
Voor de duidelijkheid is voor dit onderzoek een definitie opgesteld voor kaakgewrichtsafwijking; de subjectieve symptomen, de objectieve symptomen en Arthrosis Deformans Juvenilis zijn hiervan de samenstellende componenten. Het doel van deze begripsomschrijving was niet om aan kaakgewrichtsafwijking een nieuwe betekenis toe te kennen, maar enerzijds om kaakgewrichtsafwijking toegankelijk te maken voor statistische analyse, anderzijds om de invloed van kaakgewrichtsafwijking op de schedelbouw te onderzoeken.
Mededelingen van het kind -bij de eerste controle- over pijn, knappen of bewegingsbeperking van het gewricht zijn gerekend onder de subjectieve symptomen.

Summary

The aim of the investigation presented in this monograph is to provide insight into the origins, prevalence and significance of temporomandibular joint dysfunction in children with an Angle class II, division 1 malocclusion and into the influence of such dysfunction on the pattern of craniofacial growth.
The project was planned as an interdisciplinary investigation of the Departments of Oral Surgery and Orthodontics of the University of Groningen. The material was manipulated and analysed in close cooperation with the Project Group for Statistical Applications of the University Computer Center.
The following questions were explored:

a. What is temporomandibular joint dysfunction?
b. Does the mandible become enlarged following the moment at which deformations of the condyle -Arthrosis Deformans Juvenilis- are ascertained?
c. Does orthodontic therapy cause this deformation -Arthrosis Deformans Juvenilis?

One hundred-twelve children with an Angle class II, division 1 malocclusion were selected. Their mean age at the start of the investigation was twelve years and six months. The first documentation took place before the start of orthodontic treatment and was subsequently repeated once every twelve months; each child was documented at least four times. Orthodontic treatment received was activator or Begg therapy.
The documentary material was derived from a case history designed to trace symptoms of temporomandibular joint dysfunction, and from a clinical examination which included interrogation concerning temporomandibular joint related complaints. Data were also obtained from radiographs according to Parma, and from lateral and frontal cephalograms. Photographs were also made to increase the objectivity of some of the findings.
The customary cephalometric techniques are employed for the study of craniofacial growth. How children were selected for this study and the way in which the documentation was accumulated and adapted are described in Chapter 2.
In order to promote conceptual clarity, a definition was constructed in this investigation for temporomandibular joint dysfunction; its component parts are subjective symptoms, objective symptoms and Arthrosis Deformans Juvenilis. This conceptual specification was not intended to add a new meaning to temporomandibular joint dysfunction, but to adapt the concept in such a way that statistical analytical methods could be applied, and its influence on craniofacial growth patterns could be investigated.
Reports by the child -at the first checkup- of pain, clicking, snapping, crepitation, or restricted mobility of the joint are called **subjective symptoms**.
Clicking or snapping in the joint determined as a result of palpating at the first checkup are called **objective symptoms**.

Het tijdens deze eerste controle door middel van palperen vastgestelde knappen van het gewricht is gerekend onder de objectieve symptomen.
Duidelijke afwijkingen van het röntgenbeeld van het gewricht, geconstateerd tijdens een der controles, zijn Arthrosis Deformans Juvenilis genoemd.
De begripsbepalingen zijn vastgesteld in hoofdstuk 3. De statistische methoden, waarvan regressieanalyse en factoranalyse de belangrijkste waren, zijn kort beschreven in hoofdstuk 4.

De effecten op de craniofaciale groei zijn aangetoond in vergelijking met de kinderen met een klasse II[1] malocclusie zonder kaakgewrichtsafwijking. Deze groep kinderen diende dus als referentie (controle).
De toepassing van regressieanalyse ter verklaring van craniofaciale groei is beschreven in hoofdstuk 5. Met deze methode blijkt het mogelijk de invloed van onder andere leeftijd, geslacht, trauma en kaakgewrichtsafwijking op de schedelbouw vast te stellen.
In hoofdstuk 6 is beschreven, dat een veronderstelde invloed van kaakgewrichtsafwijking op de transversale ontwikkeling van de schedel niet aangetoond kon worden.
In hoofdstuk 7 zijn enige epidemiologische aspecten van kaakgewrichtsafwijking en Arthrosis Deformans Juvenilis beschreven. Opvallend was het frequent voorkomen van kaakgewrichtsafwijking en Arthrosis Deformans Juvenilis op reeds zeer jeugdige leeftijd (gemiddeld 12,5 jaar). Van de 112 kinderen hadden 51 kaakgewrichtsafwijking (46%). Van deze 51 hadden 23 Arthrosis Deformans Juvenilis (24%). De verdeling over beide geslachten was nagenoeg gelijk.
In hoofdstuk 8 is aangetoond dat de effecten op de craniofaciale groei en in het bijzonder op die van de mandibula voor de drie componenten waaruit kaakgewrichtsafwijking is opgebouwd onderling sterk verschillen. Met behulp van regressieanalyse zijn de componenten nader geanalyseerd. Daarbij is gebleken, dat het effect van kaakgewrichtsafwijking op de craniofaciale groei voornamelijk berust op de gezamenlijke effecten van subjectieve symptomen en Arthrosis Deformans Juvenilis.
Vanwege de geconstateerde verschillen ontstond de behoefte aan meer inzicht in de structurele samenhang van de cefalometrische waarden. Daarom zijn factoranalyses uitgevoerd, waarvan de resultaten in hoofdstuk 9 gegeven zijn.
Een deel van de resultaten van regressieanalyse en factoranalyse zijn gecombineerd in hoofdstuk 10. De syntheses zijn nader bestudeerd met behulp van structurele superpositie technieken. Bij kinderen met Arthrosis Deformans Juvenilis en bij kinderen met een trauma van de kin in de anamnese is een groeiwijze van de onderkaak vastgesteld die afwijkt van de voorwaartse groeirotatie die is waargenomen bij kinderen met een Angle klasse II[1] malocclusie zonder deze parameters.
In hoofdstuk 11 is getracht de betekenis van een

Distinct deformities of the joint visible on a radiograph, observed during one of the checkups, are called **Arthrosis Deformans Juvenilis**.
The exact definitional boundaries are given in Chapter 3. The statistical methods used, primarily regression analysis and factor analysis, are described briefly in Chapter 4.

The effects of dysfunction on craniofacial growth are demonstrated compared to children with class II, division 1 malocclusion, but without temporomandibular joint dysfunction. This group of children thus served as reference (control).
The application of regression analysis to explain craniofacial growth is described in Chapter 5. It is shown that the influence of factors such as age, sex, trauma and temporomandibular joint dysfunction on craniofacial structures can be determined with this method.
It is shown in Chapter 6 that a presumed influence exerted by temporomandibular joint dysfunction on the transversal development of the skull cannot be demonstrated.
Several epidemiological aspects of temporomandibular joint dysfunction and ADJ are described in Chapter 7. The high incidence of temporomandibular joint dysfunction and Arthrosis Deformans Juvenilis at very young ages (average twelve years and six months) was striking. Fifty-one of the one hundredtwelve children had temporomandibular joint dysfunction (46%). Twenty-three of these fifty-one had Arthrosis Deformans Juvenilis (24%). The distribution over the two sexes was virtually identical.
It is demonstrated in Chapter 8 that the effects on craniofacial growth, and especially on mandibular growth, of the three components of which temporomandibular joint dysfunction is composed differ distinctly from one another. A more thorough analysis of the component parts can be made using regression analysis. The effect of temporomandibular joint dysfunction on craniofacial growth is shown to be primarily attributable to the combined effects of subjective symptoms and Arthrosis Deformans Juvenilis.
Because of the ascertained discrepancies, the need arose to increase knowledge of the structural relationships of the cephalometric values. Factor analyses were carried out for this purpose; the results are given in Chapter 9.
Selected results of the regression analysis and factor analysis are combined in Chapter 10. The synthesis is studied further by using structural superposition techniques. A mandibular growth pattern was observed in children with Arthrosis Deformans Juvenilis and children with trauma of the chin which differed from the forward growth rotation seen in children with Angle class II, division 1 malocclusion without these parameters.
In Chapter 11 an attempt is made to indicate the significance of certain aspects of the results in the clinical situation.

deel van de resultaten voor de klinische praktijksituatie aan te geven.

De resultaten van het onderzoek rechtvaardigen de volgende conclusies:

a. Statistische pakketten zijn waardevolle hulpmiddelen bij de bewerking van grote onderzoekbestanden.

b. Regressieanalyse en factoranalyse kunnen bijdragen tot een verdieping van het inzicht in craniofaciale groei en ontwikkeling (Hoofdstuk 8.5 en 9.5).

c. De samenstellende componenten van kaakgewrichtsafwijking –subjectieve symptomen, objectieve symptomen en Arthrosis Deformans Juvenilis– zijn goede criteria voor groepsindelingen (Hoofdstuk 8).

d. Deze drie afzonderlijke componenten hebben een verschillend effect op de schedelgroei (Hoofdstuk 8.5).

e. Het is mogelijk voor de Angle klasse II^1 malocclusie een differentiaal diagnose te ontwikkelen (Hoofdstuk 10.5).

f. Wanneer bij een kind Arthrosis Deformans Juvenilis geconstateerd is kan worden verwacht dat de onderkaak een typisch aan de afwijking aangepast compenserend groeipatroon zal vertonen. Dit resulteert in een achterwaartse groeirotatie (Hoofdstuk 10.3).

g. Na een trauma van de kin bij jonge kinderen kan een zelfde groeipatroon worden verwacht als bij Arthrosis Deformans Juvenilis (Hoofdstuk 10.3).

h. Orthodontische behandeling veroorzaakt geen Arthrosis Deformans Juvenilis (Hoofdstuk 10.5).

The results of the investigation justify the following conclusions:

a. A statistical package is a valuable aid in organizing, manipulating, and analyzing data of large research projects.

b. Regression analysis and factor analysis can contribute to a deeper understanding of craniofacial growth and development (Sections 8.5 and 9.5).

c. The components of temporomandibular joint dysfunction –subjective symptoms, objective symptoms and Arthrosis Deformans Juvenilis– are good criteria for categorization (Chapter 8).

d. These three different components have a differential effect on craniofacial growth (Section 8.5).

e. It is possible to develop a differential diagnosis for the Angle class II, division 1 malocclusion (Section 10.5).

f. The mandible of a child who is diagnosed as having Arthrosis Deformans Juvenilis can be expected to display a characteristic compensatory growth pattern, resulting in a backward growth rotation (Section 10.3).

g. Following a trauma of the chin in early childhood, the same growth pattern can be expected as that seen with Arthrosis Deformans Juvenilis (Section 10.3).

h. Orthodontic treatment does not cause Arthrosis Deformans Juvenilis (Section 10.5).

17.00.0).EJ END OF JOB, ** DATE 20/04/77

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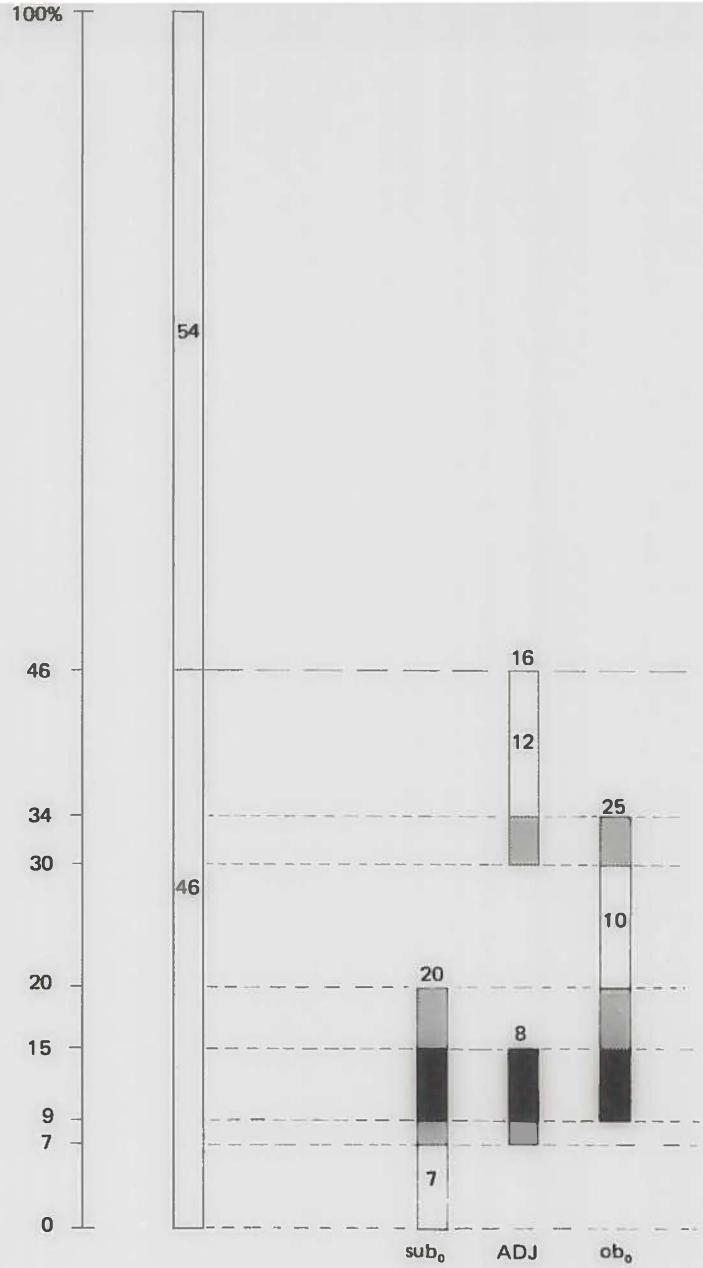
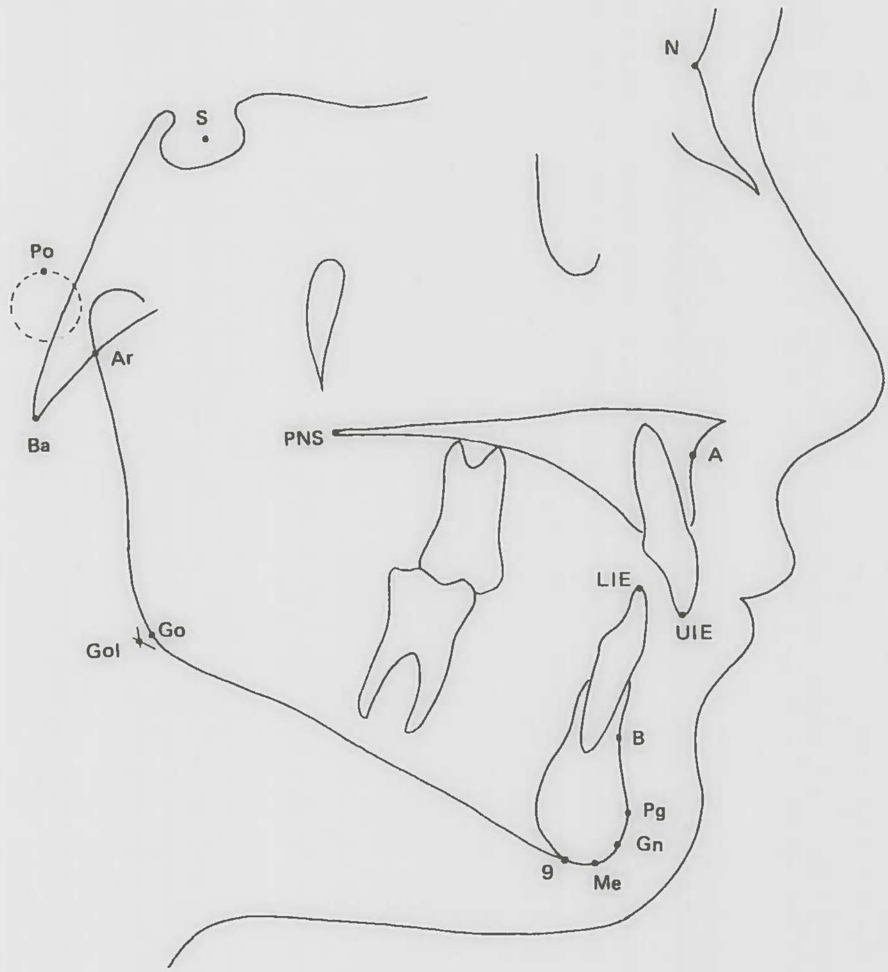


The percentage of the total number of children that displays each of the three component parts of the X-factor temporomandibular joint dysfunction is vertically plotted for each component. The percentages are also given in numbers.
Forty-six percent of the children had temporomandibular joint dysfunction. From these, 45% had subjective symptoms at year 0, 55% had objective symptoms at year 0, and ADJ was diagnosed for 49%. Thus (45+55+49)%–100%=49% of the symptoms were reported more than once.

The dysfunction was composed of
16% purely subjective symptoms,
4% subjective symptoms and ADJ,
14% subjective and objective symptoms and ADJ,
11% subjective and objective symptoms,
22% purely objective symptoms,
8% objective symptoms and ADJ,
25% ADJ.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